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ENGINEERING CALCULATIONS FOR THE "DELTA S" METHOD OF SOLVING THE ORBITAL ALLOTMENT PROBLEM

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The method of calculating single-entry separation requirements for pairs of satellites is extended to include the interference on the up link as well as on the down link. Several heuristic models for analyzing the effects of shaped-beam antenna designs on required satellite separations are introduced and demonstrated with gain contour plots. The calculation of aggregate interference is extended to include the effects of up-link interference. The relationship between the single-entry C/I requirements, used in determining satellite separation constraints for various optimization procedures, and the aggregate C/I values of the resulting solutions is discussed.

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Chapter 1

Introduction

Satellite communication has become common over the past 25 years, especially as a means of providing long distance communications. Of particular interest in this manuscript are communication satellites using the geostationary orbit (GSO). This orbit exists in the equatorial plane of the earth at a radius of 42,000 km from the center of the earth. A satellite placed in this orbit has an orbital period of 24 hours and appears to be stationary to an observer on the earth.

The Fixed Satellite Service (FSS) is the most heavily used of all of the space services using the GSO. There are a wide range of FSS networks currently in existence. These differ considerably in terms of the types of equipment used and the services provided. These services include telephony, television, teleconferencing, data transmissions, intracompany services, communications between computers, telecommunication services for remote regions and services for weather forecasting. Many frequency bands are available for use by FSS systems. The most commonly used bands are 3.7 to 4.2 GHz for down-link transmissions and 5.925 to 6.425 GHz for up-link transmissions. Other bands used are those between 10.95 and 11.2 GHz, 11.45 and 11.7 GHz, 11.7 and 12.2 GHz, and 14.0 and 14.5 GHz [1].

The systems considered in this manuscript are domestic satellites in the FSS serving a single administration. These systems are used to provide a means of communication between various earth stations within the service area of the satellite serving the administration. Regional or global systems involving satellites with service areas that may include several administrations are not considered. Direct broadcast systems are also not considered, although the methods presented here could be used for such systems with small modifications.

Use of the GSO is limited by the amount of electromagnetic interference that satellites transmitting in the same band present to each other. It is this interference which determines how closely communication satellites can be placed and thus makes the GSO a limited resource. Because of this limitation on the number of satellites which can be accommodated, the question of how to allocate this resource to the world's nations in a fair and efficient manner arises. This question has been addressed in a series of World and Regional Administrative Radio Conferences facilitated by the International Telecommunications Union (ITU). These conferences have attempted to generate orbital allotment plans for the GSO and methods of analyzing the feasibility of these plans.

The quality of an orbital allotment plan can be characterized in terms of carrier power to interference power ratios (C/I). This is the ratio of the received carrier power from a desired signal in a satellite network to the total amount of interfering signal power received from undesired signals being transmitted by other networks. When interference from all significant interferers is included in the ratio it is termed an aggregate C/I ratio. When it includes only the interference from one particular source, it is termed a single-entry C/I value. Generally, the criterion set for an acceptable orbital allotment scheme is a minimum threshold on the aggregate C/I

ratio. As long as all satellite networks in question are given orbital assignments which allow them to transmit on the specified channels with all of the resulting aggregate C/I ratios above the threshold, the scheme is satisfactory. In the calculations of this manuscript, only co-channel interference will be considered. Appendix A describes a procedure that might be used to extend the calculations to include interference from multiple channels.

The work towards developing suitable orbital allotment methods at The Ohio State University (OSU) originally involved attempts to optimize aggregate C/I values. This involved the use of nonlinear programming methods to search for assignment plans which would provide each administration with a satellite network with suitable aggregate C/I values. These methods proved to be cumbersome and slow in finding solutions for large problems [2,3].

To overcome the problems associated with nonlinear programming, linear mixed-integer programming models of the orbital assignment problem were formulated. Levis, Reilly, et. al. [4] proposed a new model for the satellite synthesis problem, which included linear constraints on the minimum spacing between satellites. These spacings or separations were calculated on a single-entry basis, i.e., the minimum required separations which satisfied some single-entry C/I requirement between all pairs of satellites in the scenario in question were calculated with a procedure developed by Wang [5]. The single-entry C/I requirement was chosen so that if this requirement were satisfied for all pairs of satellites, the resulting allotment scheme would also satisfy the aggregate C/I requirement for all satellites, even though the amount of aggregate interference present was not a factor in the procedure for finding the solution. Thus, the single-entry C/I requirement had to be sufficiently higher than the desired minimum aggregate level to insure this result. A margin of

5 dB between the desired aggregate level and the single-entry requirement was used in the calculations by Levis et. al. and Wang.

The required separation value between two satellites i and j with a particular mean orbital location θ was referred to as $\Delta\phi_{i,j}(\theta)$ (later shortened to simply $\phi_{i,j}(\theta)$) —the location-dependent separation value. The maximum of the required separation values over the entire arc was called $\Delta S_{i,j}$ (or simply $\Delta_{i,j}$). The original methods of solving the orbital allotment problem used the ΔS values as the separation constraints regardless of orbital location [4]. Other methods have since been developed which allow the use of the location-dependent separation constraints [6]. The method of using the linear constraints on satellite spacing to make the synthesis problem into a linear problem has been labeled the "Delta S" approach.

The purpose of this manuscript is to expand upon Wang's method of determining the required separation values and to examine various issues associated with the "Delta S" method. Wang's original computer program considered only interference on the down link in the required separation calculations. The goal of Chapter 2 is to provide a new method of calculating the required separation constraints which includes both up-link interference and down-link interference. In Wang's program, elliptical patterns were assumed for the satellite transmitting antennas. Chapter 3 is a preliminary study into finding reasonable methods of modelling the effects of multiple-feed shaped-beam antennas on the orbital allotment problem. Chapter 4 is an investigation of the aggregate interference problem. The relationship between single-entry interference values and the resulting aggregate interference values are examined and a new program for calculating aggregate C/I values is presented.

Chapter 2

Up-Link Interference and Its Effects on Required Satellite Separation

2.1 Description of the Problem

A communications satellite link in the Fixed Satellite Service (FSS) consists of both an up link from earth transmitters to the satellite and a down link from the satellite to receivers on the Earth. Interference from undesired transmissions can occur on either one of these links. The level of interference can be represented by the carrier to interference power ratio (C/I). This is the ratio of the carrier power received from a desired transmission to the total interference power received from other satellite networks.

In the "Delta S" approach to orbital assignments the requirements for given C/I protection ratios between satellite networks are transformed into a set of constraints on the orbital locations of the satellites. At present, the method of performing these calculations considers only the down-link interference problem. In general, for the FSS, significant amounts of interference may be introduced on both the

up link and the down link. For this reason, a modified method of calculating the minimum required separations which includes the effects of both up-link and down-link interference is proposed. These modifications are the subject of this chapter.

2.2 Up-Link C/I Calculation

The up-link interference calculations are based on the procedure described in CCIR report 455-3 [7, p. 319]. The sketch in Figure 2.1 shows the interference geometry between two satellite networks sharing an up-link frequency. In the sketch, a transmitter in administration 2 is interfering with the up-link transmission from administration 1.

Under ideal propagation conditions, the carrier power received at satellite 1 from the desired transmitter in its service area is found from the Friis transmission formula to be

$$C = \frac{P_1 G_{ET1} G_{SR1} D_{SR1}(\psi, \psi_o) \lambda_1^2}{(4\pi L_1)^2}. \tag{2.1}$$

The interference power received from a transmitter in the service area of satellite 2 is found similarly from

$$I = \frac{P_2 G_{ET2} D_{ET2}(\theta, \theta_o) G_{SR1} D_{SR1}(\alpha, \alpha_o) \lambda_2^2}{Y_u (4\pi L_2)^2}. \tag{2.2}$$

The variables listed stand for:

P: power input to earth transmitter

G: on axis gain of an antenna

D: relative gain below maximum of an antenna

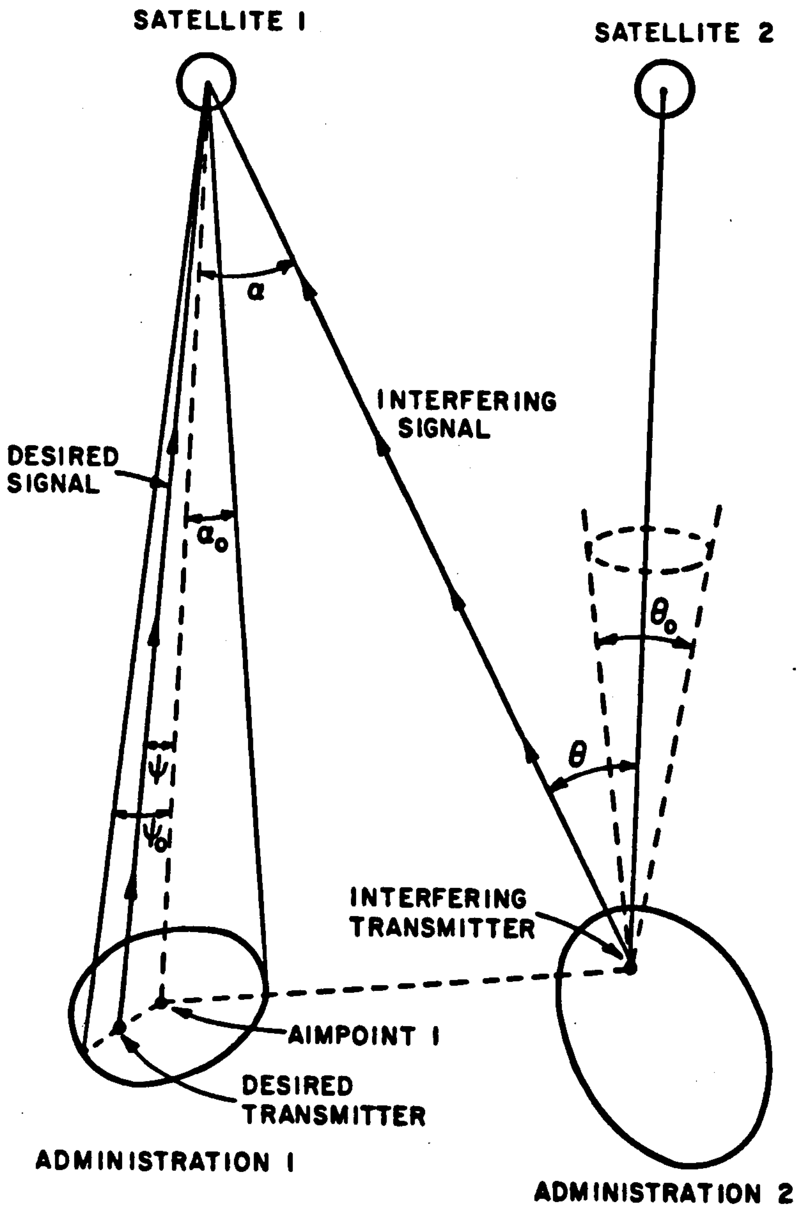


Figure 2.1: Interference geometry between administrations sharing an up-link frequency.

L: range from earth transmitter to satellite

λ: wavelength of up-link transmission

Y_u: minimum polarization discrimination between interfering up-link carrier and wanted satellite receiving antenna

α: angle between the aimpoint of the wanted satellite receiving antenna and an interfering transmitter in the other service area as seen from the satellite

θ: angle between the two satellites as seen from an interfering transmitter on the earth

ψ: angle between the aimpoint of the satellite receiving antenna and a desired transmitter in the satellite's service area as seen from the satellite .

The following subscripts have been used in the equations:

E: earth station

S: satellite

T: transmitting antenna

R: receiving antenna

1: service area from which the desired transmission originates

2: service area from which the interfering transmission originates

o: denotes the half-power beamwidth of an antenna .

The minimum possible C/I ratio at satellite 1 is then found from

$$(C/I)_{up} = \frac{P_1 G_{ET1} D_{SR1}(\psi,\psi_o)(4\pi L_2)^2 Y_u}{P_2 G_{ET2} D_{ET2}(\theta,\theta_o) D_{SR1}(\alpha,\alpha_o)(4\pi L_1)^2 M_u} \tag{2.3}$$

with: $\lambda_2 = \lambda_1$

or, working in dB, from

$$\begin{aligned} (C/I)_{up}(dB) &= P_1(dB) + G_{ET1}(dB) + D_{SR1}(\psi,\psi_o)(dB) + \\ &\quad \Delta L_u(dB) + Y_u(dB) - P_2(dB) - G_{ET2}(dB) - \\ &\quad D_{ET2}(\theta,\theta_o)(dB) - D_{SR1}(\alpha,\alpha_o)(dB) - M_u(dB). \end{aligned} \tag{2.4}$$

where: $\Delta L_u(dB) = 20\log(4\pi L_2) - 20\log(4\pi L_1)$

The term, M_u, is called the up-link margin and is defined in section 2.1 of CCIR report 455-3 [7, pp. 328-329]. Its purpose is to account for the possible reduction of the C/I ratio at the satellite due to local propagation effects and precipitation. This would occur only if the fluctuations in the power received at the satellite due to these effects was different for the interfering and desired signals. In general, this would mean that the desired and interfering transmitters were widely separated geographically. For the calculations reported here, this term is neglected (set to 1 or 0 dB).

The term, Y_u, representing the minimum polarization discrimination is also neglected. The two signals are thus assumed to have the same polarization so that there is no benefit from polarization discrimination at the satellite receiving antenna. This is in accordance with the recommendation of Rep. 455-3 in section 2.1: "In the absence of information on satellite antenna polarization, the factors Y_u

and Y_d must be set at 0 dB"[7, p. 329]. This procedure would not be followed if a suitable scheme were developed for coordinating the use of polarization among interfering administrations, and an agreement were reached on an appropriate satellite receiving antenna reference pattern for cross-polarized signals.

A further simplification in the C/I equation results from assuming that the power input to each earth station transmitter is adjusted to achieve a specified power flux density at the satellite serving the earth station. The power flux density, S, at the satellite is given by

$$S = \frac{PG_{ET}}{4\pi L^2}. \tag{2.5}$$

Thus the approximation used is

$$\frac{P_1 G_{ET1}}{4\pi L_1^2} \approx \frac{P_2 G_{ET2}}{4\pi L_2^2}. \tag{2.6}$$

This results in the following simplified form of the C/I equation,

$$(C/I)_{up} \approx \frac{D_{SR1}(\psi, \psi_o)}{D_{SR1}(\alpha, \alpha_o) D_{ET2}(\theta, \theta_o)}, \tag{2.7}$$

or in dB,

$$\begin{aligned} (C/I)_{up}(dB) \;\approx\; & D_{SR1}(\psi, \psi_o)(dB) - D_{SR1}(\alpha, \alpha_o)(dB) - \\ & D_{ET2}(\theta, \theta_o)(dB). \end{aligned} \tag{2.8}$$

It is assumed in the calculations presented here that the satellite receiving antenna is using an elliptical pattern. The -3 dB contour of the satellite receiving antenna is chosen to be the minimum size ellipse (subject to a constraint on the smallest permissible minor axis length) that completely encloses the test points

defining the service area. The ellipse is defined in a plane orthogonal to the axis of the satellite receiving antenna. Thus the half-power beamwidth of this antenna is not a constant but is a function of the plane in which it is calculated. The half-power beamwidth angles ψ_o and α_o are measured in the same planes as ψ and α, respectively, see Figure 2.1. The earth station pattern is circular, thus the half-power beamwidth denoted by θ_o is a constant.

Many reference pattern envelopes have been proposed and adopted for the satellite regulation problem. For the results reported in this chapter, the relative gains below maximum of the earth station and satellite antennas are determined from the reference pattern envelopes shown in Figures 2.2 and 2.3, respectively. The satellite antenna pattern comes from the CCIR recommendations of 1982 [8, p. 382]. The expressions of the relative gain as a function of normalized off-axis angle are

$$\begin{aligned} D_{SR}(\alpha, \alpha_o)(dB) &= -12(\alpha/\alpha_o)^2 && 0 \leq \alpha_o \leq 1.3 \\ &= -20 && 1.3 < \alpha_o \leq 3.15 \\ &= -7.5 - 25\log(\alpha/\alpha_o) && 3.15 < \alpha/\alpha_o \leq \alpha_1 \\ &= -G - 10 && \alpha_1 < \alpha/\alpha_o. \end{aligned} \tag{2.9}$$

where G is equal to the on axis gain in (dB) and $\alpha_1 = 10^{(\frac{G+2.5}{25})}$.

The ground station antenna pattern is the same one used by Wang [5, p. 23]. For this pattern, the relative gain is determined from

$$\begin{aligned} D_{ET}(\theta, \theta_o)(dB) &= -12(\theta/\theta_o)^2 && 0 < \theta \leq \theta_1 \\ &= (29 - G) - 25\log(\theta) && \theta_1 < \theta \leq \theta_2 \\ &= -G - 10 && \theta_2 < \theta. \end{aligned} \tag{2.10}$$

In this expression, θ_1 is angle at which the first two expressions are equal, i.e., $-12(\theta/\theta_1)^2 = (29 - G) - 25\log(\theta_1)$. The angle at which the second and the third expressions are equivalent is denoted by θ_2 and is found from $\theta_2 = 10^{39/25}$. G is the on axis gain of the antenna. For the calculations of this manuscript it is 43.2 dB for a 4.5 m dish at 4.0 GHz and 46.8 dB for a 4.5 m dish at 6 GHz.

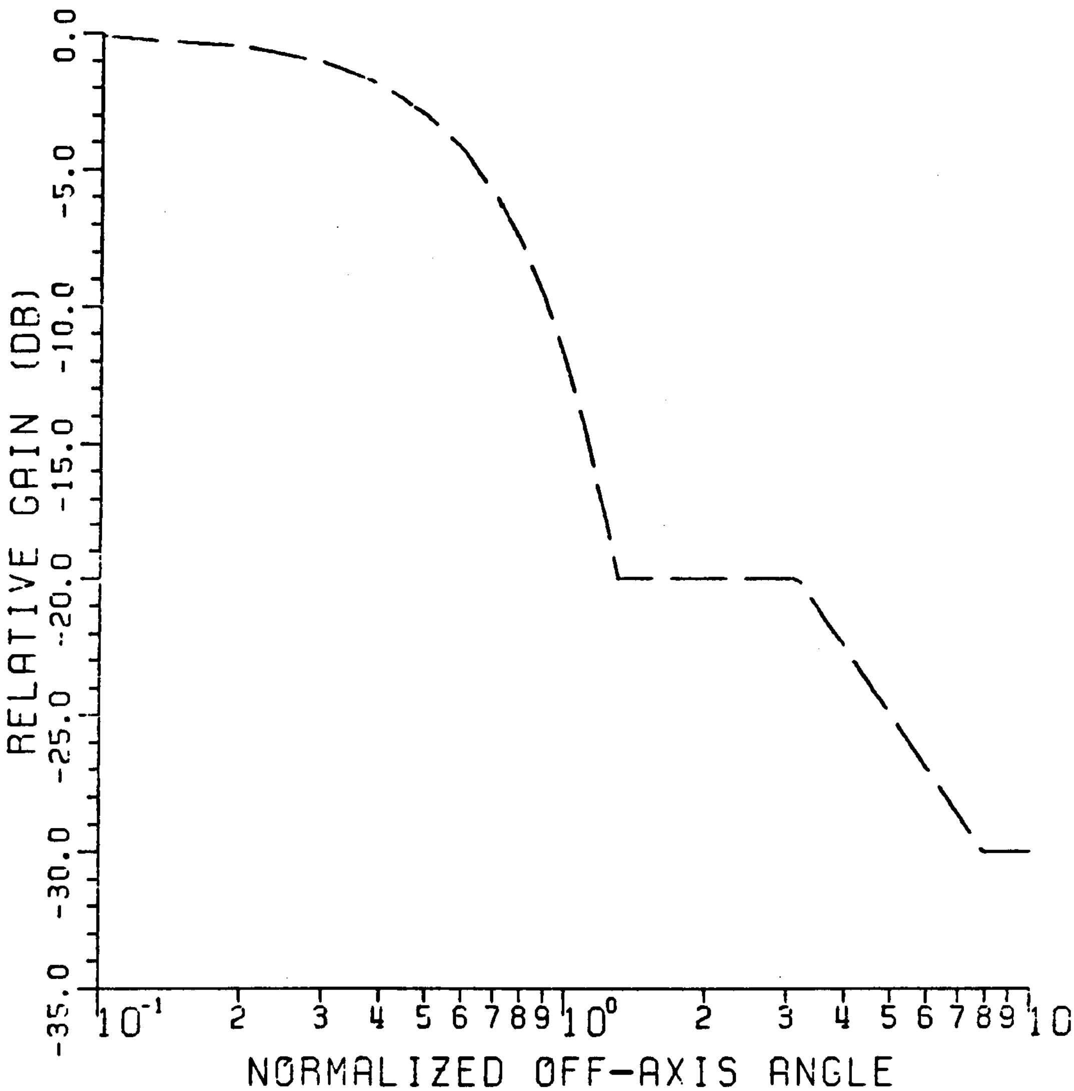


Figure 2.2: Satellite receiving antenna reference pattern (G = 30 dB in this figure for purposes of illustration).

This pattern is a modification of the ground station pattern reported in CCIR Report 391-4 [9], the modification being to change the antenna gain for values of the off-axis angle, θ, between 1 to 7 degrees from $32 - \log(\theta)$ to $29 - \log(\theta)$. This modification was suggested in Recommendation 580 of the CCIR, 1982 [10] and in the CCIR-CPM-82/RARC-83 report [11, p. 137]. It is in accordance with the FCC requirements regarding U.S. earth station antennas [12], which were designed to permit 2 degree spacing of U.S. satellites.

For purposes of comparison, the earth station gain pattern is shown in Figure 2.3 at both the transmitting frequency of 6 GHz and the receiving frequency of 4 GHz. The patterns shown are for 4.5 m parabolic dishes. The increase in the effective size of the antenna for the 6 GHz up-link signal results in approximately 3 dB more discrimination as compared to the 4 GHz down-link signal for the same satellite separation. For this reason, the worst up-link C/I ratio for each service area tends to be somewhat greater than the worst down-link C/I ratio. This depends, however, on the reference patterns used for the satellite transmitting and receiving antennas.

The minimum size ellipses used in the calculations reported here were calculated using a program developed by Akima and described in NTIA Report 81-88 [13]. The half-power beamwidth of the satellite receiving antenna, as measured in a plane containing the test point and the beam axis of the antenna, can be calculated for a given location of a transmitter on the earth's surface using the procedure described in detail in the Spectrum Orbit Utilization Program (SOUP) manual [14, pp. III.10–III.13] and summarized by Wang in his description of the original program to calculate required separation values [5, pp. 16-17].

The up-link C/I equation, equation 2.7, can be interpreted intuitively as follows.

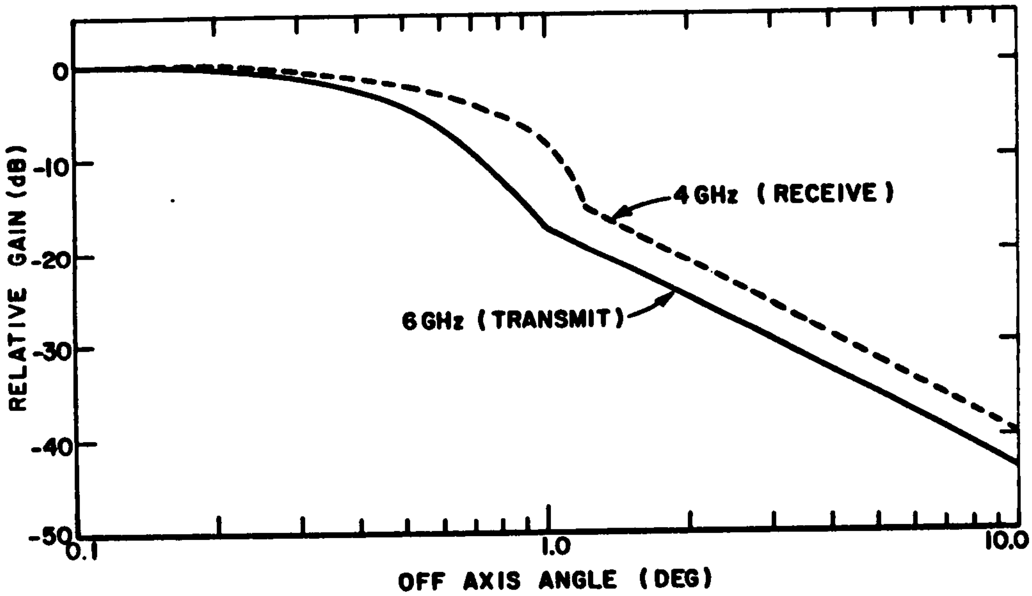


Figure 2.3: Transmitting and receiving reference patterns for ground station antennas.

The term $D_{SR1}(\psi, \psi_o)$, in the numerator, represents the amount of discrimination of the receiving antenna on the satellite to a desired signal from a transmitter in the satellite's service area. Its value will be between 0 dB and -3 dB since the -3 dB contour of the antenna is assumed to enclose the service area. In order to get an estimate of the worst case interference to the satellite system, test points are always chosen to be on the borders of the administrations. For this reason, this term can generally be approximated as -3 dB.

The term $D_{SR1}(\alpha, \alpha_o)$, in the denominator represents the amount of discrimination of the receiving antenna on the satellite to an interfering signal from a transmitter in another administration's service area. It is a measure of the geographical separation of the service areas of the desired and interfering satellites.

The third factor, $D_{ET2}(\theta, \theta_o)$, is the amount of discrimination from the earth station transmitting antenna in the interfering satellite's service area. It is a measure of how closely spaced the two satellites are and, to some extent, their location in the geostationary orbit.

A completely analogous interpretation can be given to the down-link C/I equation. The following section will follow closely the section on calculating single entry down-link C/I values in Wang's Chapter 4, section B [5, pp. 88-94]. The notation is slightly different to maintain consistency with the rest of this manuscript. The other change is that Wang wrote expressions which summed interference over many channels whereas these calculations consider only co-channel interference.

Figure 2.4 shows the interference geometry on the down link for satellite 2 interfering with satellite 1. For the down link, the carrier power received at a test point in area 1 can be determined from

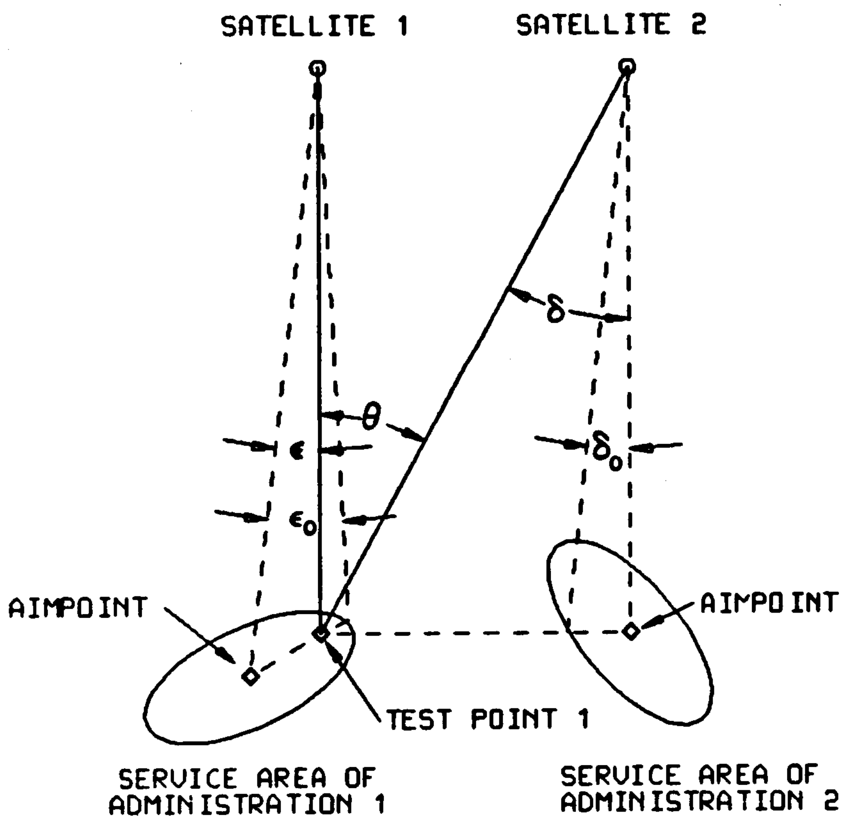


Figure 2.4: Interference geometry on the down link for satellite 2 interfering with satellite 1.

$$C = \frac{P_1 G_{ST1} D_{ST1}(\epsilon, \epsilon_o) G_{ER1} \lambda_1^2}{(4\pi L_1)^2}. \tag{2.11}$$

The interference power received from satellite 2 is

$$I = \frac{P_2 G_{ST2} D_{ST2}(\delta, \delta_o) G_{ER1} D_{ER1}(\theta, \theta_o) \lambda_1^2}{(4\pi L_2)^2}. \tag{2.12}$$

The same notation is used here as was used in deriving the up-link expressions. Note that the satellite transmitting antennas are assumed to be using elliptical patterns. The angle δ represents the off-axis angle from the aimpoint of satellite 2 to the test point while δ_o represents the half-power beamwidth of the elliptical beam as measured in a plane containing the test point and the beam axis. Similarly, ϵ represents the off-axis angle from the aimpoint of satellite 1 to the test point, while ϵ is the half-power beamwidth.

The C/I ratio can be expressed as

$$(C/I)_{down} = \frac{P_1 G_{ST1} D_{ST1}(\epsilon, \epsilon_o)(4\pi L_2)^2}{P_2 G_{ST2} D_{ST2}(\delta, \delta_o) D_{ER1}(\theta, \theta_o)(4\pi L_1)^2}. \tag{2.13}$$

Using the approximation

$$\frac{P_1 G_{ST1}}{L_1^2} \approx \frac{P_2 G_{ST2}}{L_2^2}, \tag{2.14}$$

the equation simplifies to

$$(C/I)_{down} \approx \frac{D_{ST1}(\epsilon, \epsilon_o)}{D_{ST2}(\delta, \delta_o) D_{ER1}(\theta, \theta_o)}. \tag{2.15}$$

In the simplified down-link equation, equation 2.15, the important terms are the interfering satellite transmitting antenna discrimination, $D_{ST2}(\delta, \delta_o)$, and the earth station receiving antenna discrimination, $D_{ER1}(\theta, \theta_o)$. The discrimination, $D_{ST2}(\delta, \delta_o)$, increases with increasing geographical distance between the two service areas and $D_{ER1}(\theta, \theta_o)$ increases with increased orbital spacing.

2.3 Computer Program To Calculate Required Separation

The computer program, "DELTA", to compute the minimum required separations for all pairs of satellites works to satisfy a specified total link C/I ratio. The link C/I ratio for each service area is found by first finding the worst up-link and down-link C/I ratios for each area. The FORTRAN code for this program is listed in Appendix B.

The worst up-link C/I is found by performing an up-link calculation for all interfering transmitter test points in the interfering satellite's service area. The location of the desired transmitter in the satellite's service area is fixed at the test point which is closest to the -3 dB contour of the receiving antenna. A selection of possible satellite receiving antenna patterns and earth station transmitting antenna patterns is offered to the user. For the calculations presented in this manuscript, the patterns displayed in section 2.1 have been used.

Similarly, the worst down-link C/I is found by performing a down-link calculation at each receiver test point in the satellite's service area. These calculations are performed using the procedure and equations described by Wang in his chapter on the "Delta-S" method [5, pp. 86-106]. Again, a selection of possible antenna patterns for the satellite and the earth station are offered. Elliptical patterns are used for the satellite transmitting antenna while the earth station antenna uses a circular beam. The power flux density at the aimpoints of all satellites is assumed to be equal to a constant. This is the same assumption made by Wang.

The link C/I ratio is then found by assuming that the C/I ratio on the transmission from the satellite is the same as that which is received by the satellite. This

results in the following expression.

$$(C/I)_{link}^{-1} = (C/I)_{up}^{-1} + (C/I)_{down}^{-1} \tag{2.16}$$

This equation is really a worst case assumption that implies that the satellite does not do any on board processing of the signal but merely converts it from 4 GHz to 6 GHz and transmits it back to the earth. With current technology, it is feasible to have on board processing and error correction capability for digital signals [15, p. 9-2]. In a system of this type, if interference on the up link induced bit errors at the satellite receiver, these could be detected and corrected before transmission back to the earth. An alternative to the procedure used in these calculations would be to set a lower limit on the up-link C/I ratio and a separate limit on the down-link C/I ratio and to space the 2 satellites the minimum distance apart for which both requirements were satisfied.

The program calculates required separation values at uniform increments over the intersection of the two feasible arcs for all combinations of two satellites. The feasible arc of an administration is defined to be the range of possible satellite orbital locations for which an observer at any test point in the satellite's administration can view the satellite at an elevation angle no lower than a predetermined limit. The elevation angle limit has been taken to be 10 degrees for the calculations reported here. In other work, this limit has to be relaxed to 3 or 5 degrees when performing calculations for polar nations, such as Canada, from which the GSO is visible only at low elevation angles.

The flow chart displayed in Figure 2.5 illustrates the procedure used in the program. A binary search is used to locate the minimum required separation at each orbital location considered. The orbital location is the mean longitude of

the satellites; throughout the search process, the two satellites are spaced equally about this location. First, the two satellites are separated by a distance equal to the initial trial solution of 3 degrees at the eastern most location of the intersection of the two feasible arcs. For the first satellite, up-link C/I values are calculated, using equation 2.7, for interfering transmitters located at every test point in the interfering satellite's administration and the worst value is saved. Down-link C/I values are calculated, using equation 2.13, at every test point in the satellite's administration and the worst value is saved. The link C/I for the first administration is then found. This process is then repeated for the second satellite and its administration. The lower of the two worst case link C/I ratios is then compared to the lower limit set for the link C/I ratio. If the C/I ratio is below the limit then the spacing between the satellites is increased in equal increments until a spacing is found for which the worst case link C/I ratio is above the limit. If the C/I ratio is above the limit, then the spacing between satellites is decreased in equal increments until a spacing is reached where the worst case link C/I is below the limit. In this way, an upper and lower bound on minimum required satellite separation is found. The two satellites are then spaced by an amount equal to the average of the upper and lower bound. The worst case link C/I is then recalculated and compared to the limit. If it is too low, then the lower bound on satellite separation is set to the present value of satellite separation. If it is too high then the upper bound on satellite separation is set to the present value of satellite separation. This process is repeated until the resulting worst case link C/I is within the predetermined margin of error of the lower limit.

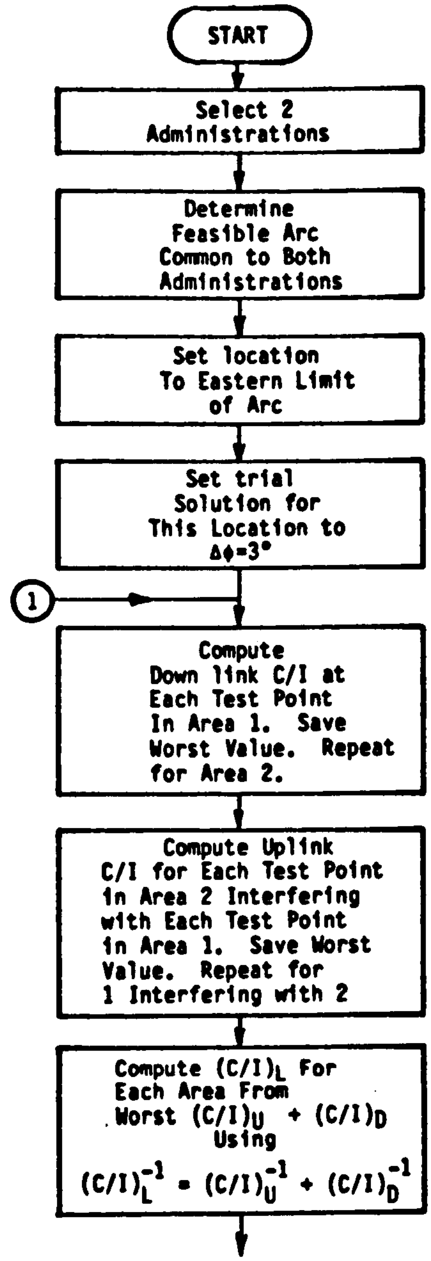
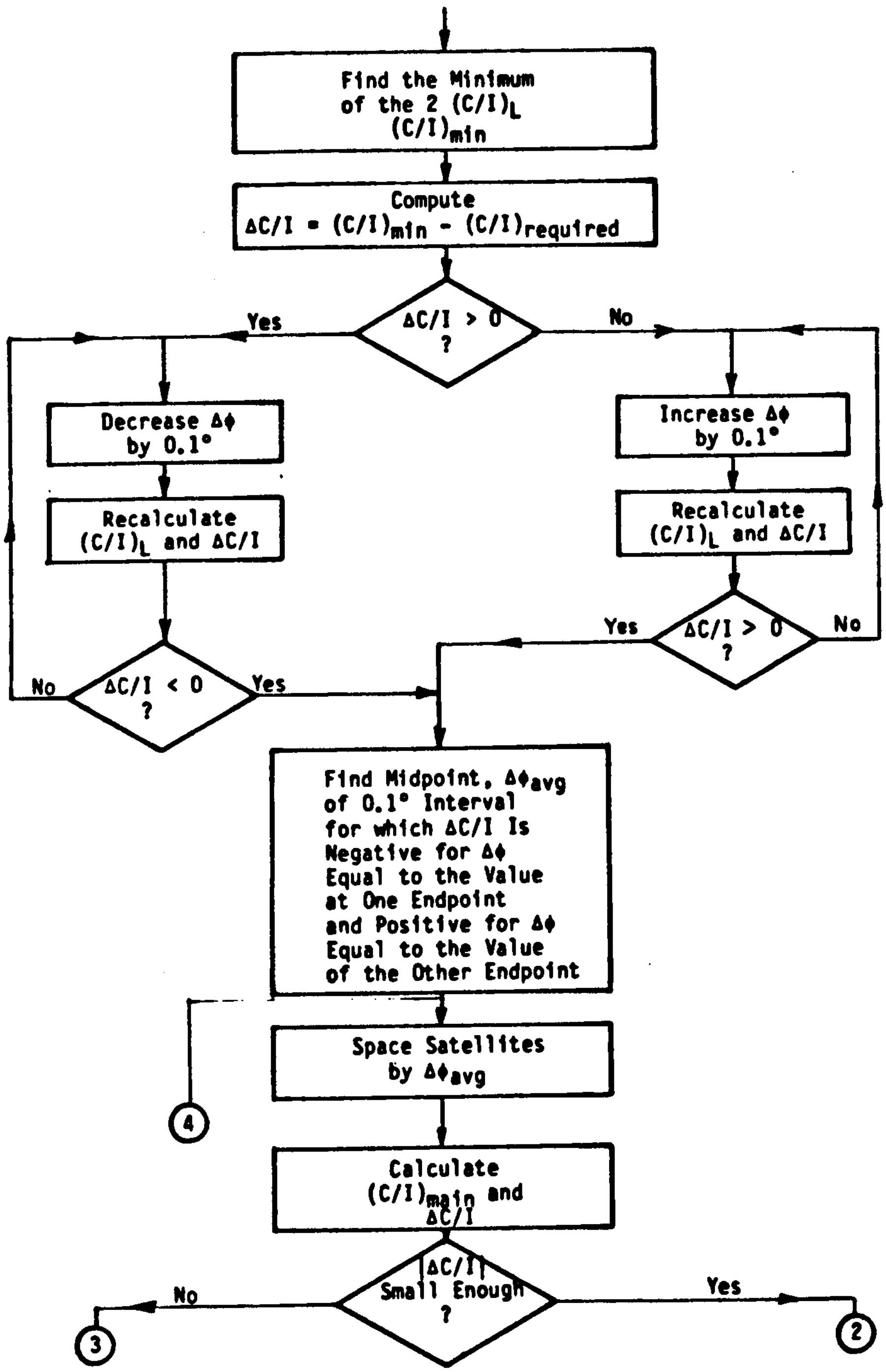


Figure 2.5: Flow chart of procedure used in program "DELTA" (cont. on two following pages).

(Figure 5 cont.)

(From Page 21)



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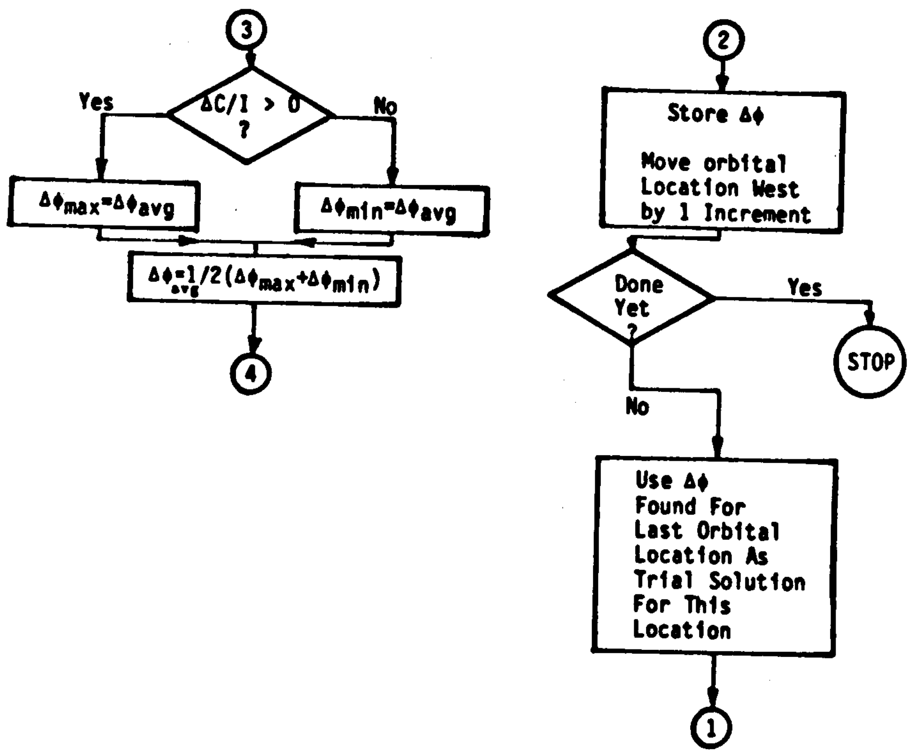


The two satellites are then moved west to the next position in the arc for which a separation value is to be determined and the process described above is repeated. Now, however, instead of using 3 degrees as the initial trial solution, the value calculated at the eastern most location is used. Since the required separation values do not, in general, change drastically over the orbital arc, this is a good estimate of the required separation. After the required separation value is found for this location, the satellites are again moved to the west to the next location in the arc for which values are to be calculated. This process is continued until they have been calculated at all required positions.

To speed up the calculations, it is assumed that, for small changes in the locations of the satellites, the only angle used in the C/I calculations which will change significantly is the angle of separation between the two satellites as seen from the earth stations. This is a reasonable approximation since the coverage patterns of the satellite antennas change very slightly as the location of the satellite is changed slightly. Thus only the angle labeled θ in Figure 2.1 needs to be recalculated during each iteration.

The "DELTA" computer program is designed to be used as one step in solving the satellite synthesis problem. The starting point for the synthesis problem is a set of administrations to be provided with one satellite each. The service areas of the administrations are defined by sets of test points. The test points are points on the surface of the earth which represent the vertices of a polygon circumscribing each administration's service area. The test points are specified by their latitude and longitude. The number of test points needed to define a service area depends on its size and shape and ranges from 4 to 12.

The second stage of the process is to generate the minimum ellipse data for

each administration's service area using Akima's program. This must be done at many locations in the feasible arc of each administration as the minimum ellipse may change significantly from one end of the feasible arc to the other. In addition to the test points defining the service areas of each administration, information must be input to Akima's program concerning the error tolerance on each ellipse, including satellite pointing error and orientation-angle error and a constraint on the minimum size of a beamwidth. For the calculations of this report, the minimum-size beamwidth has been chosen to be 0.6 degrees, the pointing error to be 0.1 degrees and the orientation-angle error to be 1 degree. The output of Akima's program is the minimum ellipse data for the administrations at each orbital location considered. Each ellipse is specified by five parameters: the longitude and latitude of the aimpoint of the antenna on the earth, the major axis and minor axis beamwidths of the elliptical beam, and the orientation angle of the ellipse. The orientation angle is defined as the angle measured in a counterclockwise direction, in a plane orthogonal to the antenna axis, from a line parallel to the equatorial plane to the major axis of the ellipse.

The third stage of the process is the new program to calculate required separation values described in this report. The following information which applies to all administrations must be input to this program:

1. The minimum link, single-entry C/I requirement to be met for all satellites.

2. Up-link and down-link frequencies at which calculations are to be performed.

The following additional information must be input for every administration:

1. Service area data of each administration in the form of the test points described earlier.

2. The minimum ellipse data calculated by Akima's program.

3. Reference patterns to be used for the satellite receiving antenna, satellite transmitting antenna, ground station receiving antenna, and ground station transmitting antenna.

4. Diameter of parabolic earth station antennas for transmitting and receiving.

5. Information on range of feasible arc for the administration.

The output of the program is the required separation data. This is output in two forms. One is a matrix of maximum required separation values, for every pair of administrations. The second is a set of required separation matrices, calculated at orbital locations specified by the user. These are the $\Delta\phi$ values for the orbital locations considered.

The next stage in solving the synthesis problem is to use the required separation data in linear constraints in the various formulations for the orbital allotment problem developed by the Industrial and Systems Engineering Department at OSU. These formulations and the computer programs to implement them have been described in detail in several reports [3,4,6]. The ultimate output of these programs is a list of feasible solutions for the allotment problem, specifying an orbital location for each administration's satellite.

The final stage in the process is to analyze the possible solutions to the allotment problem. Aggregate C/I ratios are calculated for each administration using a program which will be described in detail in Chapter 4. In this way, the quality of each proposed solution can be checked.

2.4 Results

The plots displayed in Figures 2.6 through 2.9 illustrate the variation of the minimum required satellite separation values for various administrations in South America. The plots have been calculated over the extent of the feasible arc common to both administrations. The plots are parametric in $(C/I)_L$, the minimum required link C/I ratio, and have been generated using the program described earlier. For these runs it has been assumed that each ground station in both administrations is using a 4.5 m dish for receiving and transmitting. The calculations have been performed at the nominal FSS up-link frequency of 6 GHz and the nominal down-link frequency of 4 GHz.

These curves exhibit roughly the same variation over the feasible arc as those reported earlier [5,16] in which up-link interference was not considered. That is, the maximum required separation between two service areas generally occurs near the ends of the arc that can be used by satellites of both administations. This occurs for two reasons.

First, when the two satellites are located at the ends of the arc, the topocentric angle of separation between the two satellites as seen from the earth is smaller than it is when they are located at the midpoint of the arc, for a given longitudinal, or geocentric, angle of separation. This phenomenon is illustrated in Tables 2.1 and 2.2. These tables show the resulting topocentric angle of separation seen by an observer on earth, when two satellites are separated by a given geocentric angle. This angle is a function of the latitude of the location of the observer on earth and the longitudinal separation between the location of the observer and the satellite pair. The geometry of the situation is displayed in Figure 2.10. Table 2.1 shows

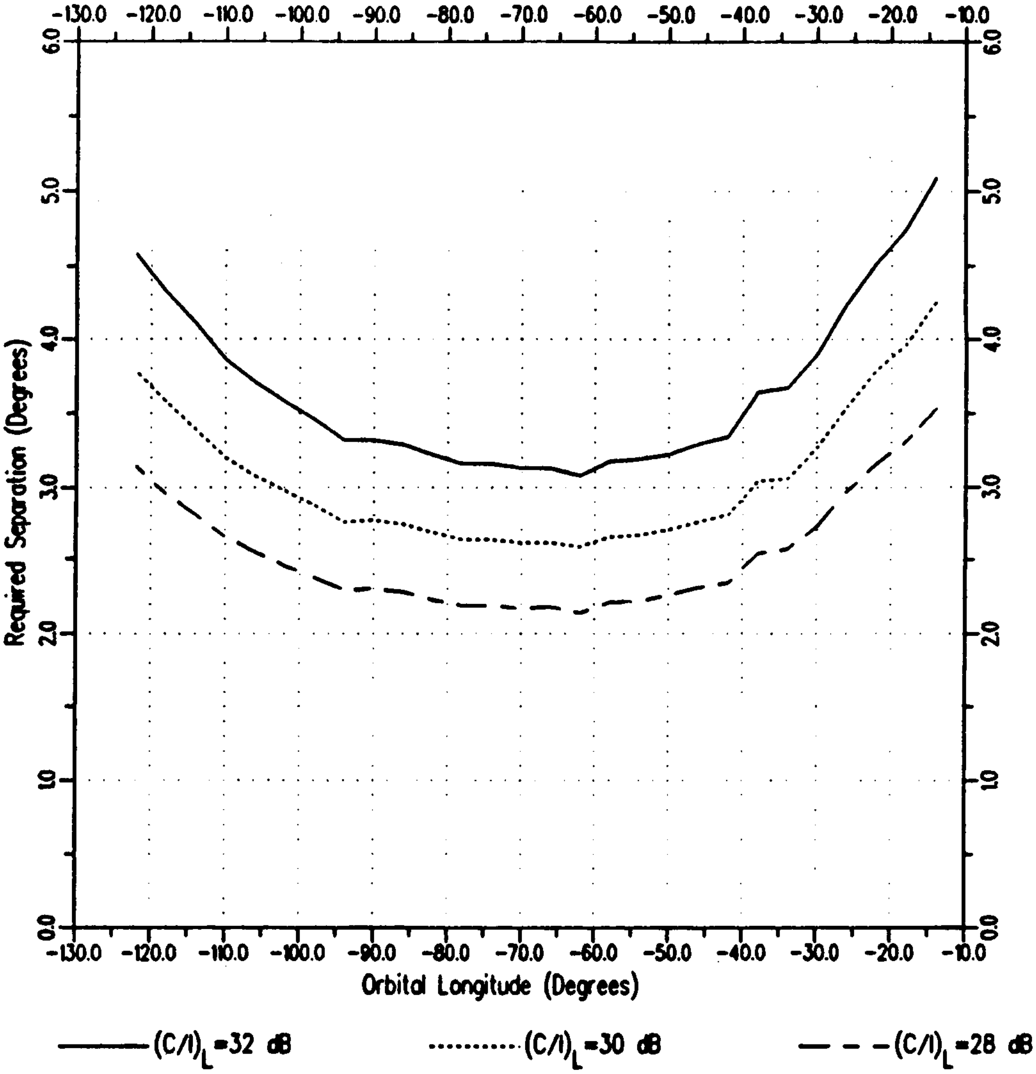


Figure 2.6: Required separation as a function of position for satellites serving Chile and Paraguay.

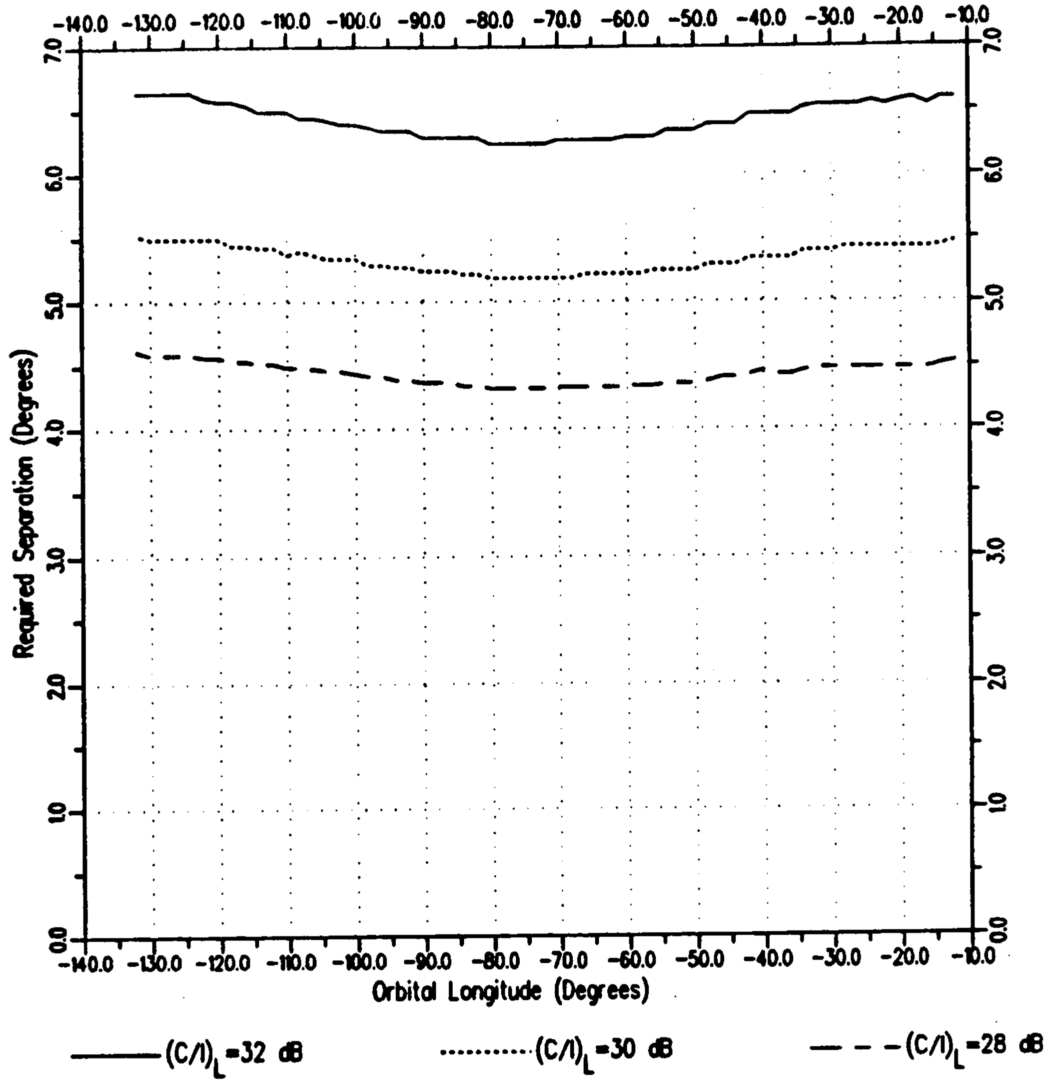


Figure 2.7: Required separation as a function of position for satellites serving Columbia and Venezuela.

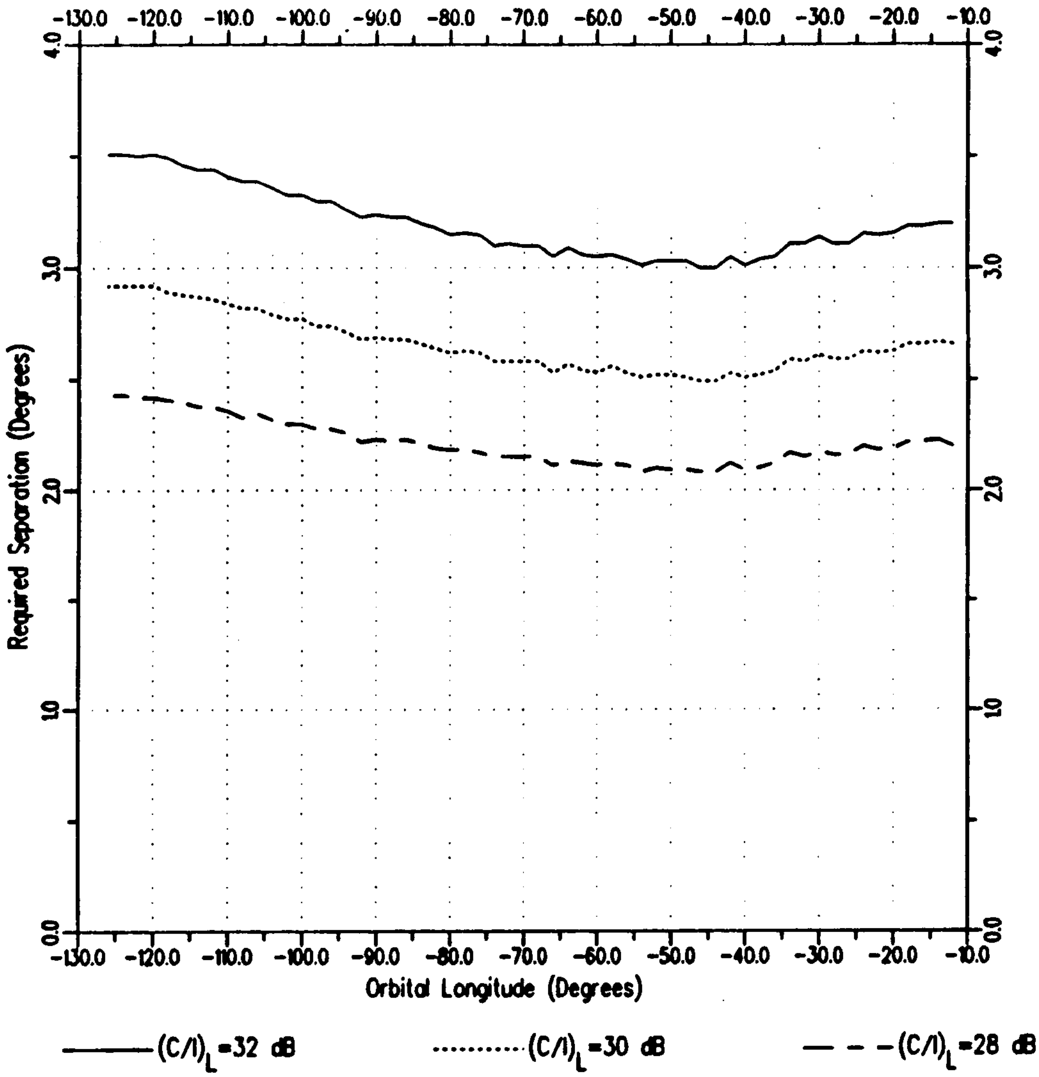


Figure 2.8: Required separation as a function of position for satellites serving Columbia and Bolivia.

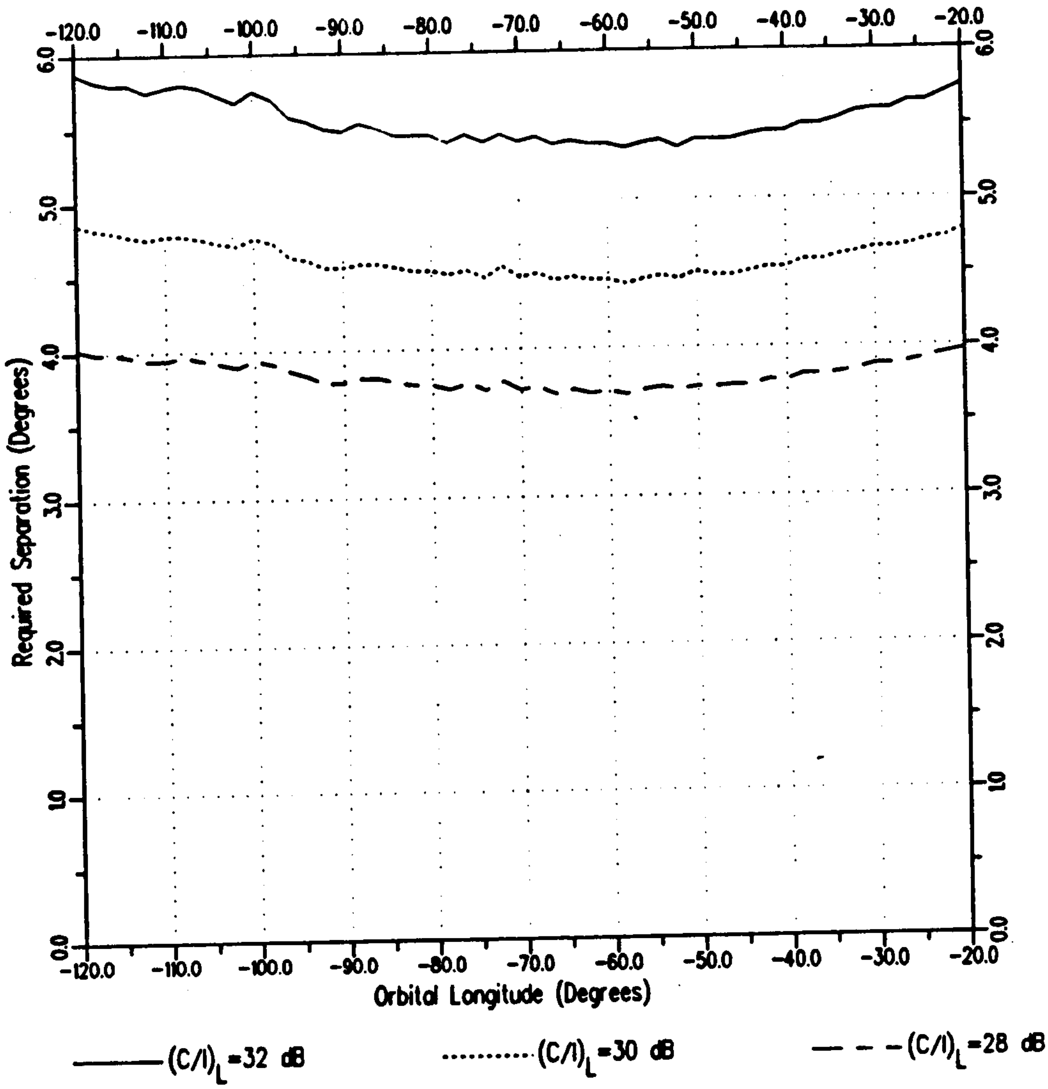
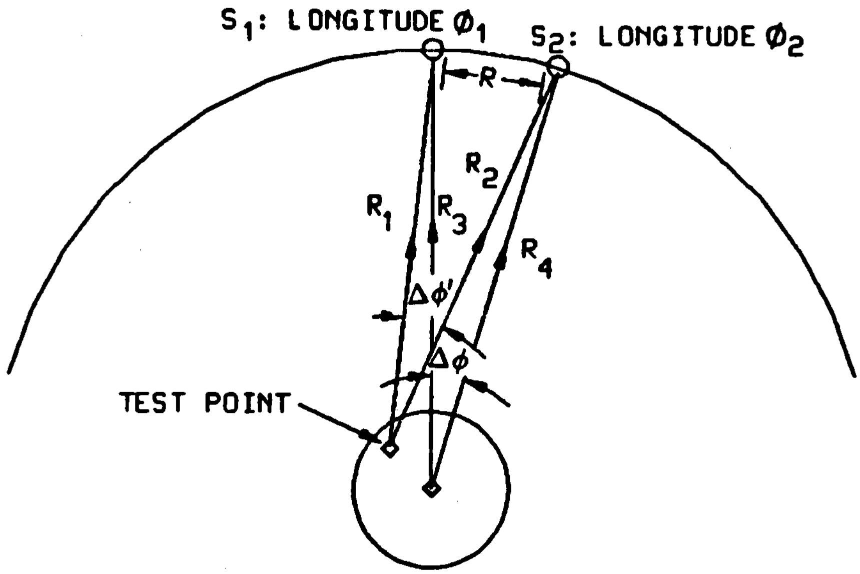


Figure 2.9: Required separation as a function of position for satellites serving Argentina and Bolivia.

the topocentric angle of spacing for a fixed geocentric spacing of two degrees. This has been calculated for an observer at latitudes of 0, 20, 40, and 60 degrees and for satellite locations ranging from directly overhead to 60 degrees in longitude away from the observer. The resulting transmitting discrimination at 6 GHz and receiving discrimination at 4 GHz for a 4.5 m dish on the ground at an off-axis angle equal to the topocentric angle calculated is also displayed. Table 2.2 shows the same results for a geocentric angle of spacing of 4 degrees.

The second reason why the spacing requirement can be much larger at the ends of the arc involves the coverage of a satellite transmitting or receiving pattern for administrations with irregular shapes. A satellite located at $-14°$ W, for example, transmitting a signal to Chile, will necessarily send a great deal more interfering power into neighboring countries than will a Chilean satellite at $-60°$ W. This occurs because the administration can not be fitted with a tight ellipse at the ends of the arc.

This is illustrated in Figures 2.11 through 2.13. Figure 2.11 shows the gain contours for a satellite at $-14°$ W with an antenna using an elliptical pattern either transmitting a signal to Chile or receiving a signal from a Chilean transmitter. The contours have been calculated and are displayed in a plane orthogonal to the satellite antenna axis, as viewed from the satellite. The X axis of the plot was chosen to correspond to an axis parallel to the equatorial plane of the earth. A more detailed description of the routine to calculate these contours is found in Chapter 3. Test points in the nearby country of Paraguay have also been projected onto the plane orthogonal to the axis and plotted to show the extent of the transmitted power spillover for the specific case illustrated in Figure 2.6, i.e., the interaction between Paraguay and Chile. Distances on the plot are measured in terms of the radius of



$\Delta\phi$: geocentric angle of separation

$$\Delta\phi = \phi_2 - \phi_1$$

$\Delta\phi'$: topocentric angle of separation

$$\Delta\phi' = \arccos\left(\frac{R_1^2 + R_2^2 - R_5^2}{2R_1R_2}\right)$$

$$R_5^2 = R_3^2 + R_4^2 - 2R_3R_4\cos(\Delta\phi)$$

Figure 2.10: Relationship between geocentric and topocentric angles of separation.

Table 2.1: Changes in the apparent angle between two satellites and the resulting earth station antenna discrimination with longitudinal separation of the satellites and the observer and the latitude of the observer. The geocentric angle of separation is 2 degrees.

Longitudinal Separation Observer/Satellite (deg.)	Topocentric Angle (deg.)	Gain Below Max. Transmitting (dB)
Earth Observer at Latitude = 0 Degrees		
0.00	2.36	-27.11
10.00	2.35	-27.07
20.00	2.32	-26.95
30.00	2.28	-26.77
40.00	2.23	-26.53
50.00	2.18	-26.26
60.00	2.12	-25.96
Earth Observer at Latitude = 20 Degrees		
0.00	2.33	-26.97
10.00	2.32	-26.93
20.00	2.30	-26.83
30.00	2.26	-26.66
40.00	2.22	-26.45
50.00	2.17	-26.19
60.00	2.11	-25.92
Earth Observer at Latitude = 40 Degrees		
0.00	2.25	-26.60
10.00	2.24	-26.57
20.00	2.23	-26.49
30.00	2.20	-26.37
40.00	2.17	-26.20
50.00	2.13	-26.01
60.00	2.09	-25.79
Earth Observer at Latitude = 60 Degrees		
0.00	2.14	-26.07
10.00	2.14	-26.06
20.00	2.13	-26.01
30.00	2.12	-25.94
40.00	2.10	-25.84
50.00	2.07	-25.72
60.00	2.05	-25.60

Table 2.2: Same as Table 2.1 but with the satellites separated by a geocentric angle of 4 degrees.

Longitudinal Separation Observer/Satellite (deg.)	Topocentric Angle (deg.)	Gain Below Max. Transmitting (dB)
Earth Observer at Latitude = 0 Degrees		
0.00	4.71	-31.03
10.00	4.70	-30.99
20.00	4.65	-30.88
30.00	4.57	-30.69
40.00	4.47	-30.46
50.00	4.36	-30.18
60.00	4.24	-29.89
Earth Observer at Latitude = 20 Degrees		
0.00	4.65	-30.90
10.00	4.64	-30.86
20.00	4.59	-30.75
30.00	4.52	-30.59
40.00	4.43	-30.37
50.00	4.33	-30.12
60.00	4.23	-29.85
Earth Observer at Latitude = 40 Degrees		
0.00	4.50	-30.52
10.00	4.49	-30.50
20.00	4.45	-30.42
30.00	4.40	-30.29
40.00	4.34	-30.13
50.00	4.26	-29.93
60.00	4.18	-29.72
Earth Observer at Latitude = 60 Degrees		
0.00	4.28	-30.00
10.00	4.28	-29.98
20.00	4.26	-29.94
30.00	4.23	-29.86
40.00	4.19	-29.77
50.00	4.15	-29.65
60.00	4.10	-29.52

Table 2.3: Spillover of Chilean Elliptical Pattern Into Paraguay For Chilean Satellites Located at $-110°W, -60°W$, and $-14°W$.

Test Point in Paraguay		Antenna Discrimination At This Location (dB)		
Lat. (deg)	Long. (deg)	-110 W	-60 W	-14 W
-25.3	-57.6	-11.34	-18.66	-5.08
-27.3	-58.6	-10.77	-15.00	-3.17
-27.2	-56.2	-13.78	-20.00	-5.69
-25.5	-54.7	-15.07	-20.00	-8.89
-24.1	-54.2	-15.07	-20.00	-10.90
-20.2	-58.1	-8.39	-19.84	-8.19
-19.3	-59.1	-6.87	-17.36	-7.67
-20.5	-62.2	-4.33	-9.23	-3.71
-22.2	-62.7	-4.43	-7.66	-2.53

the earth, R_e. Figure 2.12 shows the gain contours for a Chilean satellite located at $-60°$ W while Figure 2.13 shows the contours when the satellite is at $-110°$ W. Table 2.3 shows this effect numerically. For each test point in Paraguay, the amount of discrimination received from a satellite transmitting antenna serving Chile is listed when the satellite is located at $-14°$ W, $-60°$ W and $-110°$ W. This is also the discrimination that the receiving antenna on the Chilean satellite provides to an up-link interference signal originating from that point in Paraguay. Note that for the worst test point in Paraguay, the discrimination increases from -7.66 dB down from the maximum at $-60°$ W to -2.53 dB down from the maximum at $-14°$ W. At $-110°$ W it is -4.43 dB below maximum.

This helps illustrate why the required separation plots for Paraguay and Chile show a sharper increase in required separation at the ends of the arc than do the plots for countries with more regular shapes. Less discrimination is provided by the satellite antennas at the ends of the arc so more discrimination must be provided

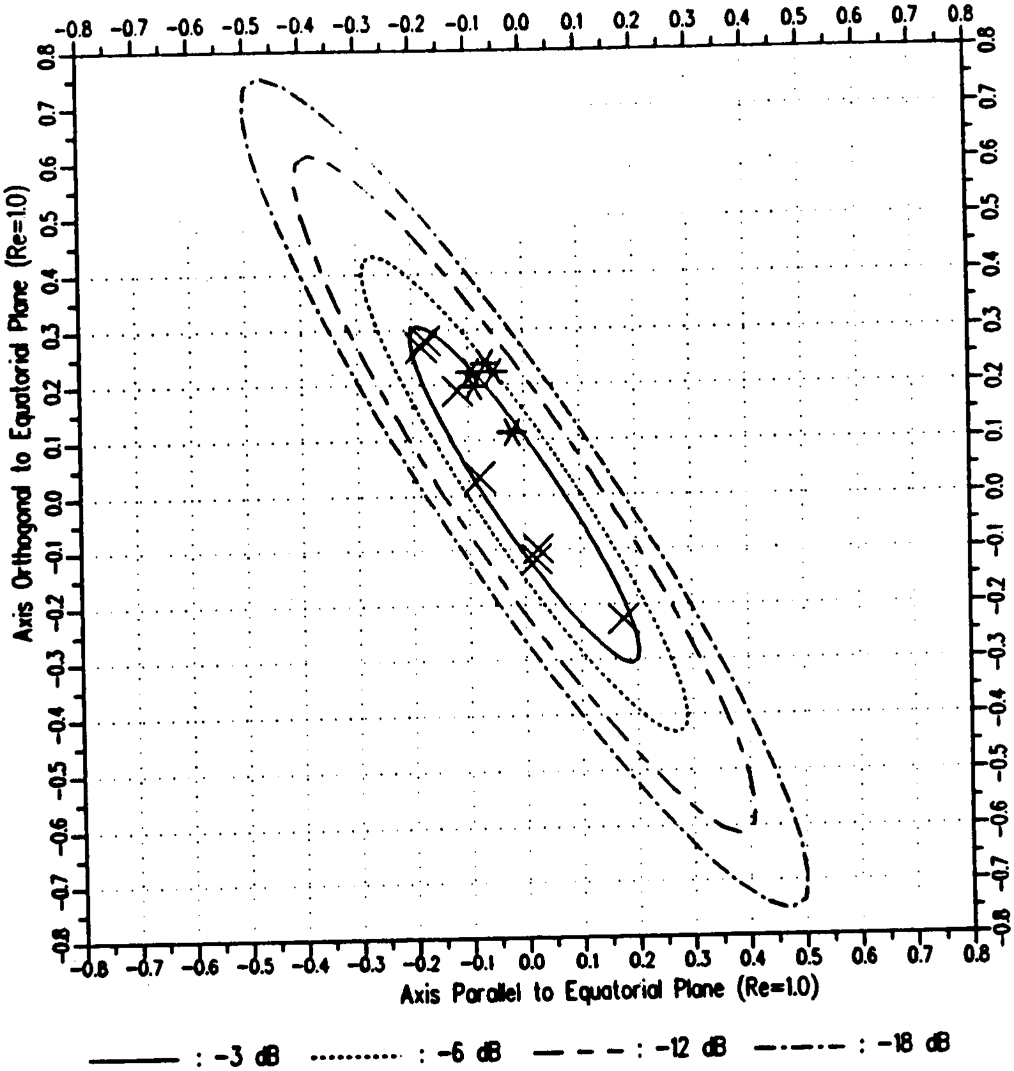


Figure 2.11: Elliptical pattern gain contours for Chilean satellite at $-14°$ W (X Chilean Test Point * Paraguayan Test Point).

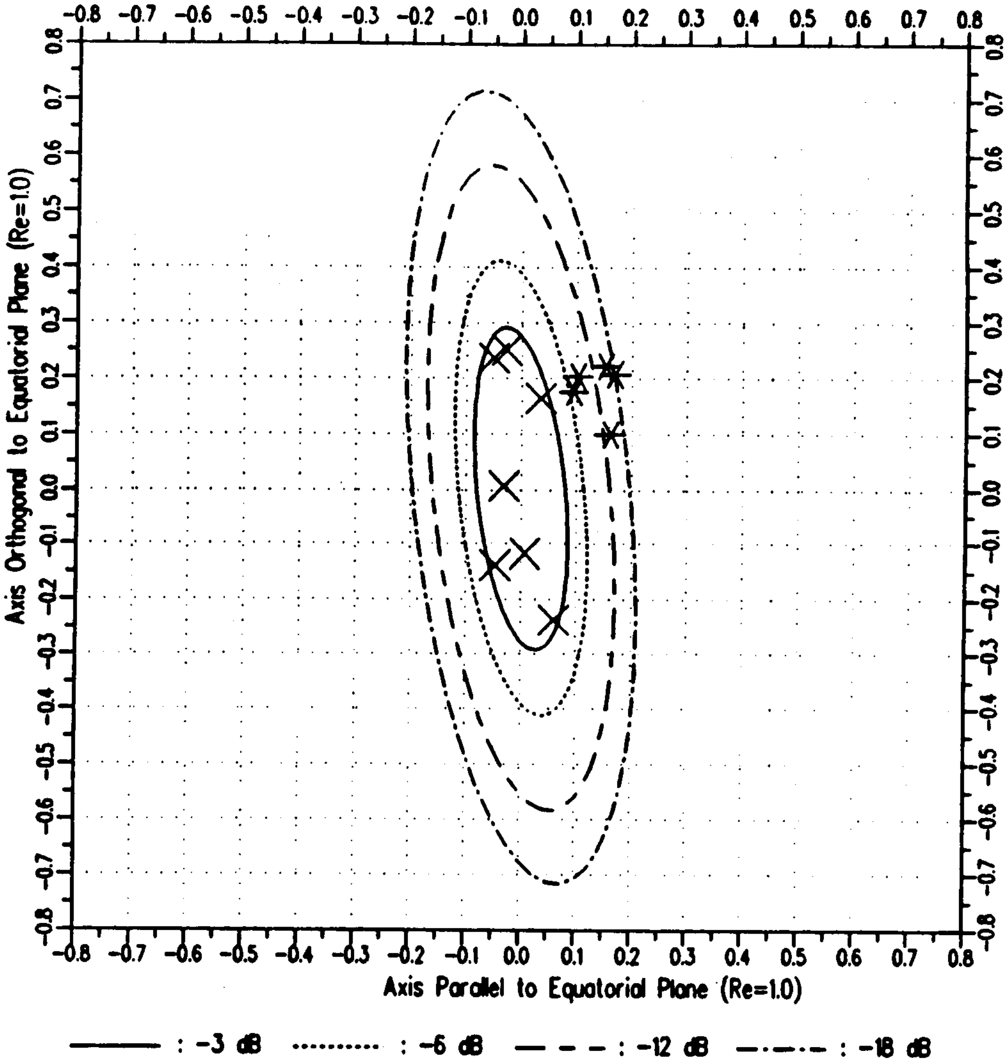


Figure 2.12: Elliptical pattern gain contours for Chilean satellite at $-60°$ W (X Chilean Test Point * Paraguayan Test Point).

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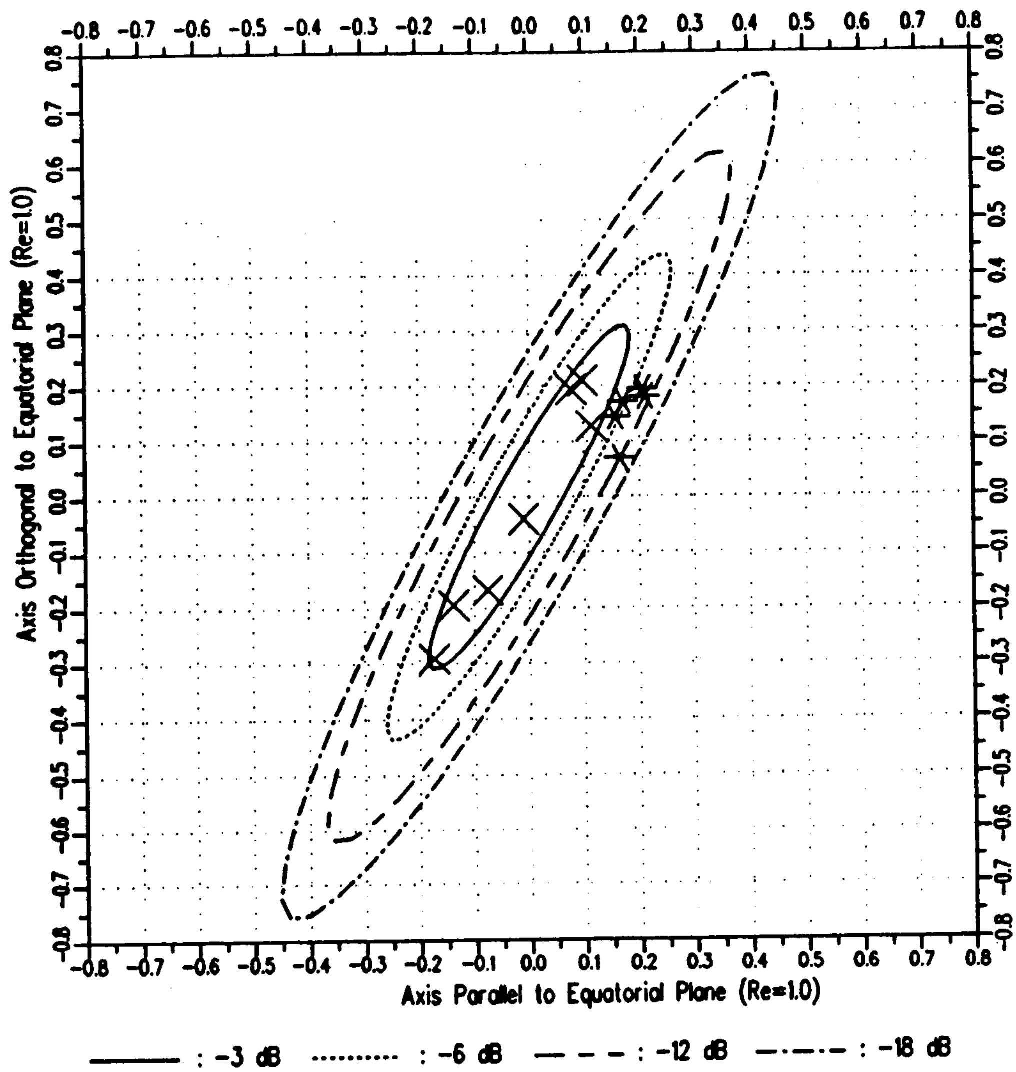

Figure 2.13: Elliptical pattern gain contours for Chilean satellite at $-110°$ W (X Chilean Test Point * Paraguayan Test Point).

Table 2.4: Required Separation Matrix For South America, $(C/I)_L = 30$ dB.

	Brazil	Guyana	Paraguay	Uruguay	Argentina	Venezuela	Bolivia	Chile	Columbia	Peru	Ecuador
Surinam	4.88	5.09	1.13	0.78	1.21	4.17	1.17	1.86	2.36	1.43	1.12
Fre. Guiana											
Brazil		5.39	5.22	4.84	5.39	4.93	5.09	4.22	5.44	5.60	3.46
Guyana			1.16	0.93	1.20	5.28	1.27	1.75	2.91	1.79	1.13
Paraguay				3.28	4.97	1.16	4.83	3.86	1.31	2.95	1.13
Uruguay					4.74	1.10	2.19	3.60	1.09	1.61	1.01
Argentina						1.20	4.84	5.24	1.47	3.54	1.38
Venezuela							1.30	1.85	5.56	3.10	2.42
Bolivia								5.03	2.91	5.19	1.61
Chile									2.20	4.95	2.40
Columbia										5.05	4.78
Peru											5.07

Maximum Required Separation in Degrees Over Arc

by the earth station antennas. This requires more satellite spacing.

Table 2.4 shows the maximum required separation matrix for South American administrations where both up-link and down-link interference has been included. It has been calculated at $(C/I)_L = 30$ dB.

the up-link and down-link expressions. This symmetry results in a relationship between the values of up-link interference and down-link interference between the satellite networks serving two administrations.

The test points in one administration that are closest to the aimpoint of the second administration's satellite as measured in terms of the normalized off-axis

angle (δ/δ_o) will tend to receive the worst interference from that satellite as the term $D_{ST2}(\delta,\delta_o)$ in the down-link equation, equation 2.13, will be the greatest. When these test points are used as the sites for transmitters on the up-link, however, they will likewise present the most serious interference to the second administrations up-link transmissions as the term $D_{SR1}(\alpha,\alpha_0)$ in the up-link equation, equation 2.7, will also be the greatest. The other factors in these two expressions show less variation from test point to test point. In general, if one administration receives significantly more interference on the down link than the other administration, it will receive less interference on the up link.

The following two examples illustrate this point. The first shows the interference between a Brazilian satellite at $-52.57°$ W and an Argentine satellite at $-47.43°$ W. The two satellites are spaced by the value of $\phi_{i,j}$ of 5.14 degrees at $-50°$ W. Table 2.5 lists the resulting C/I ratios. The down-link C/I ratios are displayed for both administrations at every test point in each. The up-link C/I values at each administration's satellite are shown at each test point for the interfering transmitter in the other administration's service area. The test point for the desired up-link transmitter in each administration's service area is fixed at the one which results in the lowest C/I values. The up-link C/I actually changes only slightly with the location of this point, however. All C/I values are listed from the best to the worst when moving down within a column.

Table 2.6 lists the same thing for the interference between a Chilean satellite at $-111.61°$ W and a Paraguayan satellite at $-108.39°$ W. Note that the receivers in Paraguay receive a great deal of interference. This is due to the spillover of the Chilean ellipse at this orbital location described earlier. The Paraguayan satellite receives significantly less interference on the up-link transmissions. For the Chilean

receivers on the ground, however, the interference is significantly better than for those in Paraguay. The Chilean satellite receives much worse interference on the up-link transmissions, however.

Table 2.5: Up-link and down-link interference between an Argentine satellite at $-47.43°$ W and a Brazilian satellite at $-52.57°$ W.

Brazilian C/I Ratios

Down link		Up link Brazilian Transmitter at (2.0,-70)	
Location of Receiver	Down-link (C/I) (dB)	Location of Argentine Transmitter	Up-link (C/I) (dB)
4.50,-52.00	51.16	-50.0,-73.5	43.53
5.10,-60.00	51.03	-55.0,-66.0	43.45
-7.50,-34.80	50.63	-43.0,-72.2	41.98
2.00,-70.00	50.56	-32.0,-70.4	39.29
-22.50,-42.00	47.95	-37.0,-56.5	38.33
-7.50,-73.50	46.70	-28.0,-69.2	38.23
-11.50,-70.50	41.70	-22.0,-66.0	36.55
-22.50,-57.80	33.69	-22.0,-63.0	36.05
-32.50,-52.50	33.15	-26.2,-53.6	35.76
-30.00,-57.50	31.17		

Argentine C/I Ratios

Down link		Up link Argentine Transmitter at (-55.0,-66.0)	
Location of Receiver	Down-link (C/I) (dB)	Location of Brazilian Transmitter	Up-link (C/I) (dB)
-50.00,-73.50	40.63	4.50,-52.00	54.62
-55.00,-66.00	40.36	-7.50,-34.80	54.52
-43.00,-72.20	39.45	5.10,-60.00	54.48
-37.00,-56.50	36.85	2.00,-70.00	54.47
-32.00,-70.40	36.50	-7.50,-73.50	50.57
-28.00,-69.20	35.30	-22.50,-42.00	50.18
-22.00,-63.00	34.06	-11.50,-70.50	44.91
-22.00,-66.00	33.60	-32.50,-52.50	37.05
-26.20,-53.60	32.92	-22.50,-57.80	35.94
		-30.00,-57.50	34.90

Table 2.6: Up-link and down-link interference between an Paraguayan satellite at -111.61° W and a Chilean satellite at -108.39° W.

Paraguayan C/I Ratios

Down link		Up link Paraguayan Transmitter at (-19.3,-59.1)	
Location of Receiver	Down-link (C/I) (dB)	Location of Chilean Transmitter	Up-link (C/I) (dB)
-25.5,-54.7	43.78	-56.0,-69.0	51.47
-24.1,-54.2	43.53	-46.0,-76.0	50.47
-27.2,-56.2	41.87	-18.5,-71.5	49.51
-25.3,-57.6	40.38	-34.0,-72.0	49.35
-27.3,-58.6	38.08	-44.0,-71.0	49.17
-20.2,-58.1	35.97	-17.6,-70.0	48.98
-19.3,-59.1	33.64	-23.0,-66.5	37.02
-22.2,-62.7	31.37		
-20.5,-62.2	31.16		

Chilean C/I Ratios

Down link		Up link Chilean Transmitter at (-56.0,-69.0)	
Location of Receiver	Down-link (C/I) (dB)	Location of Paraguayan Transmitter	Up-link (C/I) (dB)
-34.0,-72.0	47.53	-24.1,-54.2	46.13
-56.0,-69.0	47.52	-25.5,-54.7	46.11
-46.0,-76.0	47.28	-27.2,-56.2	44.59
-44.0,-71.0	46.36	-25.3,-57.6	41.78
-18.5,-71.5	46.16	-27.3,-58.6	41.12
-17.6,-70.0	45.99	-20.2,-58.1	38.43
-23.0,-66.5	33.69	-19.3,-59.1	36.71
		-22.2,-62.7	33.94
		-20.5,-62.2	33.83

Chapter 3

Modelling The Effects of Shaped-Beam Antennas On The Required Separation Calculations

3.1 Introduction

To this point, the required satellite separation calculations have been made under the assumption that the satellite antennas are transmitting elliptical gain patterns. That is, the loci of constant directivity in a plane perpendicular to the beam are ellipses for all values of directivity. The -3 dB contour of the satellite antenna has been set to correspond to the smallest ellipse which completely encloses the service area. In practice, however, a beam can be shaped to more closely follow the border of the service area of a satellite than a single elliptical beam can. One common practice is to use a multiple-feed antenna to cover the service area with a beam composed of many smaller spot beams rather than with a single large ellipse.

The use of a multiple-feed shaped-beam antenna has two main advantages over simply covering a service area with a beam of simpler shape. One advantage is that much less power will be transmitted to areas outside the service area with

the shaped-beam antenna. The directivity of the shaped-beam antenna will fall off more rapidly outside the -3 dB contour circumscribing the service area than it will for a single elliptical pattern. A second advantage is that a more uniform main beam illumination level can be achieved. The directivity of the antenna inside the service area will be more uniform than with an elliptical beam.

No method of calculating the resultant interference from shaped-beam antennas to regions outside their service areas has yet been adopted by the CCIR. For this reason, work has been done to develop guidelines for making this calculation. It would be a hopeless task to attempt to predict in any detail what antenna designs and shaped-beam contours might be implemented on satellites launched in the future which have not even been proposed yet. However, it should be possible to develop reasonable gain contours which more closely reflect the capabilities of shaped-beam antenna technology than do simple elliptical patterns.

Note that all of the methods presented have limitations. All are heuristic methods which attempt to make reasonable assumptions about the nature of shaped-beam antennas which might be used on future satellites. Rather than being generally applicable, all of them are based on particular assumptions which may or may not be valid for a given service area. Care would have to be used in extending the methods considered here to a service area which consists of two or more disjoint land areas; two obvious examples of such service areas are Japan and the United Kingdom. A further limitation is that no detailed data on the radiation patterns of real shaped- beam satellite antennas in areas outside the satellite's service area has been obtained with which to compare these models. Thus, this chapter should be regarded as only a preliminary study of various ideas for modelling shaped beams and an examination of whether the results that they produce are sensible.

Several papers of interest concerning this topic can be cited. H. Akima describes one method for modelling the effects of shaped-beam antennas in the reference manual to GSOAP [17]. This is similar to the "uniform rolloff" method described in this chapter, in that it determines relative gain as a function of the distance from the service area polygon. Akima [18] has also presented a model for calculating the antenna gain in the direction of an earth point from several contour lines given on the map of the earth. In a recent paper, Rao and Moody [19] develop a model for specifying the radiation envelope of shaped-beam antennas for use in planning the FSS. The model is described primarily in terms of local beamwidth size and peak sidelobe level.

Four methods of modelling the gain rolloff from a shaped-beam antenna will be presented here. The first is a simple method which uses an elliptical -3 dB pattern but a modified rate of gain rolloff from this contour. The other three are attempts to predict the nature of shaped-beam gain contours which would be implemented for a service area based on the geographical shape of the service area. All methods are discussed in detail in sections 3.2 and 3.3. Section 3.4 presents graphical plots of the gain contours which result when these methods are used. Section 3.5 presents an analysis of the effects of using one of these methods on the required separation calculations.

3.2 Elliptical Half-Power Patterns

The first method investigated is based on a reference pattern published in the Final Acts of RARC-83 [20, p. 150]. In this pattern, the rate of rolloff is modified to reflect the capabilities of multiple-feed shaped-beam antennas. It is elliptical only

inside the half-power, -3 dB, relative gain contour. The governing equations are:

$$
\begin{array}{lll}
D(\alpha,\alpha_o)(dB) & = -12(\alpha/\alpha_o)^2 & 0 \le \alpha/\alpha_o \le 0.5 \\
& = -18.75\alpha_o^2\left[(\alpha/\alpha_o) - X\right]^2 & 0.5 < \alpha/\alpha_o \le 1.16/\alpha_o + X \\
& = -25.23 & 1.16/\alpha_o + X < \alpha/\alpha_0 \le 1.45 \\
& = -22 - 20\log(\alpha/\alpha_o) & 1.45 < \alpha/\alpha_o \\
& = -G & -G > -22 - 20\log(\alpha/\alpha_o)
\end{array}
\tag{3.1}
$$

$$X = 0.5(1.0 - 0.8/\alpha_o).$$

In this expression, G is the on-axis gain of the antenna, α is the off-axis angle to the test point, and α_o is the half-power beamwidth of the antenna measured in a plane containing the test point and the beam axis of the antenna.

Note that for this reference pattern, outside the -3 dB contour, the relative gain is no longer a function only of the ratio (α/α_o) but of the actual values of the off-axis angle and the measured half-power beamwidth. Thus this pattern does not give rise to uniformally elliptical gain contours as do the satellite antenna patterns agreed upon in earlier conferences. Wang [5, p. 22] reported results with a modified version of this pattern which was suggested by a CCIR-CPM-82 report. This version of the pattern is identical to the one listed above for small values of α but gives more antenna discrimination for larger values. It is listed below:

$$
\begin{array}{lll}
D(\alpha,\alpha_o)(dB) & = -12(\alpha/\alpha_o)^2 & 0 \le \alpha/\alpha_o \le 0.5 \\
& = -18.75\alpha_o^2\left[(\alpha/\alpha_o) - X\right]^2 & 0.5 < \alpha/\alpha_o \le 1.265/\alpha_o + X \\
& = -30 & 1.265/\alpha_o + X < \alpha/\alpha_o \le 1.585 \\
& = -24 - 30\log(\alpha/\alpha_o) & 1.585 < \alpha/\alpha_o \\
& = -G & -G > -24 - 30\log(\alpha/\alpha_o)
\end{array}
\tag{3.2}
$$

$$X = 0.5(1.0 - 0.8/\alpha_o).$$

The same procedure is used to calculate the relative gain of the satellite antenna using these patterns as with the uniform elliptical patterns. That is, the minimum size ellipse which covers the service area for a particular orbital location of the

satellite serving the area must be specified. These ellipses are found using Akima's computer program [13] and are defined in a plane orthogonal to the beam axis. The half-power beamwidth, α_o, is calculated in a plane which contains the beam axis and the test point. Once the off-axis angle is found from the antenna axis to the point on the surface of the earth for which the gain is being calculated, the relative gain is calculated from the equations listed earlier.

3.3 Methods Using Service Area Polygons

The other three methods of modelling the gain contours from shaped-beam antennas all involve working in a plane orthogonal to the satellite antenna axis. In each of these methods, it is assumed that it is acceptable to work in this plane rather than on the spherical surface about the satellite on which its antenna patterns are defined because of the large length of the GSO radius compared to the relatively small dimensions of the service areas involved.

3.4 Coordinate Systems

The starting point for these methods is the set of test points given in terms of latitude and longitude which describes the service area of an administration and a satellite location denoted by its longitude. For the computer programs presented here it is necessary to have a convention regarding the order in which these test points are specified, so that it is clear how they are connected and which direction is the interior of the service area. This has been chosen as follows: the test points are entered in the order they must be connected to form a polygon circumscribing the service area so that, if one draws a line between successive points, the interior

of the service area will always be on the left hand side.

Several different rectangular coordinate systems will be used in the calculations presented in this chapter. The first, is the earth-centered coordinate system, i.e., a system whose origin is the center of the earth. The z axis is the axis of the earth and passes through the earth's poles. The y axis is selected so that it runs through the Prime Meridian (0 degrees longitude). The most natural way of specifying points on the earth or in the GSO is with spherical coordinates (R, θ, ϕ) where R represents the radius from the center of the earth, θ is the latitude of the point and ϕ is the longitude. To convert from spherical coordinates to the earth-centered rectangular coordinates, the following transformation is performed

$$\begin{aligned} z &= R\sin\theta \\ y &= R\cos\theta\sin\phi \\ x &= R\cos\theta\cos\phi. \end{aligned} \tag{3.3}$$

Distances in this report will be measured in units of Earth radii. Thus for points on the surface of the earth, R = 1.0 . For points in the GSO, R is approximately 6.6134. The earth's radius is denoted by R_e.

A second coordinate system that will be used is one centered at the aimpoint of the antenna of the satellite serving the administration in question. Aimpoints are selected for the satellite antennas of each administration at all orbital locations considered. The exact locations of these aimpoints are not crucial, though it must generally be close to the center of an administration's service area. For the calculations presented here, the aimpoint from Akima's minimum ellipse program for the given satellite location has been used. The aimpoint is specified by its latitude and

longitude, (θ_a, ϕ_a). Its earth-centered coordinates are given by

$$\begin{aligned} z_a &= R \sin\theta_a \\ y_a &= R\cos\theta_a \sin\phi_a \\ x_a &= R\cos\theta_a \cos\phi_a. \end{aligned} \tag{3.4}$$

A satellite's orbital location is specified by its longitude only, since the latitude of the GSO is 0 and its radius is approximately 6.6134 times the earth radius. Given a satellite's orbital location, ϕ_s, the earth centered coordinates of the satellite are

$$\begin{aligned} z_s &= 0 \\ y_s &= 6.6134 \sin\phi_s \\ x_s &= 6.6134 \cos\phi_s. \end{aligned} \tag{3.5}$$

The aimpoint-centered coordinate system is selected as follows. The x' axis extends from the aimpoint through the satellite's location in the GSO. The y' axis is chosen to be parallel to the equatorial plane of the earth and orthogonal to the x' axis. The z' axis is then taken to be orthogonal to the x' and y' axes. This is depicted in Figure 3.1. To derive the transformation from the earth-centered coordinate system to the aimpoint-centered coordinate system, the unit vectors $(\hat{x}', \hat{y}', \hat{z}')$ will be derived in terms of the unit vectors $(\hat{x}, \hat{y}, \hat{z})$ of the earth-centered system.

The unit vector $\hat{x}'$ is in the same direction as the vector from the satellite antenna's aimpoint to the satellite. It is found from

$$\hat{x}' = \frac{(x_s - x_a)\hat{x} + (y_s - y_a)\hat{y} - z_a\hat{z}}{\sqrt{(x_s - x_a)^2 + (y_s - y_a)^2 + z_a^2}}. \tag{3.6}$$

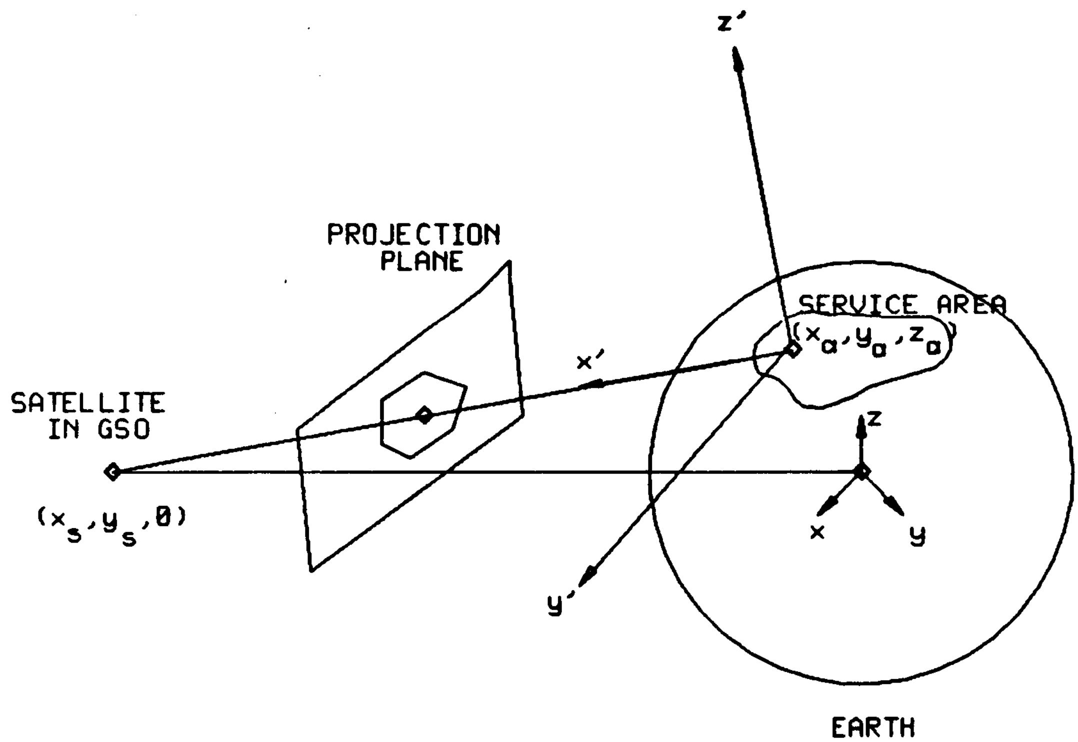

Figure 3.1: Aimpoint-centered coordinate system for use in gain contour plots and shaped-beam calculations.

The unit vector $\hat{y}'$ must be orthogonal to $\hat{x}'$ and $\hat{z}'$. It also must be orthogonal to $\hat{z}$ since the y' axis is parallel to the equatorial plane. Let

$$\hat{y}' = a\hat{x} + b\hat{y} + 0\hat{z}, \tag{3.7}$$

where

$$a^2 + b^2 = 1, \tag{3.8}$$

and

$$\hat{x}' \cdot \hat{y}' = 0. \tag{3.9}$$

Then the dot product of $\hat{x}'$ and $\hat{y}'$ is

$$\hat{x}' \cdot \hat{y}' = \frac{a(x_s - x_a) + b(y_s - y_a)}{\sqrt{(x_s - x_a)^2 + (y_s - y_a)^2 + z_a^2}}. \tag{3.10}$$

Setting the dot product to zero yields

$$a(x_s - x_a) + b(y_s - y_a) = 0. \tag{3.11}$$

Now, substituting for b and solving for a produces

$$a(x_s - x_a) + \sqrt{(1 - a^2)}(y_s - y_a) = 0, \tag{3.12}$$

$$a^2 = \frac{(y_s - y_a)^2}{(x_s - x_a)^2 + (y_s - y_a)^2}, \tag{3.13}$$

and

$$a = \frac{\pm(y_s - y_a)}{\sqrt{(x_s - x_a)^2 + (y_s - y_a)^2}}. \tag{3.14}$$

Choosing the "–" sign and solving for b gives

$$b^2 = \frac{(x_s - x_a)^2 + (y_s - y_a)^2 - (y_a - y_s)^2}{(x_s - x_a)^2 + (y_s - y_a)^2}, \tag{3.15}$$

or

$$b = \frac{\pm(x_s - x_a)}{\sqrt{(x_s - x_a)^2 + (y_s - y_a)^2}}. \tag{3.16}$$

The "+" sign must be selected here to force the dot product to zero. Thus the expression for $\hat{y}'$ is

$$\hat{y}' = \frac{(y_a - y_s)\hat{x} + (x_s - x_a)\hat{y}}{\sqrt{(x_s - x_a)^2 + (y_s - y_a)^2}}. \tag{3.17}$$

The remaining unit vector $\hat{z}'$ can now be found using the cross product. To simplify the expressions, let

$$R_1 = \sqrt{(x_s - x_a)^2 + (y_s - y_a)^2 + z_a^2}, \tag{3.18}$$

and

$$R_2 = \sqrt{(x_s - x_a)^2 + (y_s - y_a)^2}. \tag{3.19}$$

Now $\hat{z}'$ is found from

$$\hat{z}' = \hat{x}' \times \hat{y}', \tag{3.20}$$

or

$$\hat{z}' = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \frac{(x_s - x_a)}{R_1} & \frac{(y_s - y_a)}{R_1} & \frac{-z_a}{R_1} \\ \frac{(y_a - y_s)}{R_2} & \frac{(x_s - x_a)}{R_2} & 0 \end{vmatrix}. \tag{3.21}$$

Thus, $\hat{z}'$ is found from

$$\hat{z}' = \hat{x}\left[\frac{z_a(x_s - x_a)}{R_1 R_2}\right] + \hat{y}\left[\frac{z_a(y_s - y_a)}{R_1 R_2}\right] + \hat{z}\left[\frac{(x_s - x_a)^2 + (y_s - y_a)^2}{R_1 R_2}\right]. \tag{3.22}$$

Since the origin of the new coordinate system is chosen to be the aimpoint, a point given in earth-centered coordinates, (x, y, z), can be represented in aimpoint-centered coordinates, (x', y', z'), by the transformation

$$x' = \left[\frac{(x_s - x_a)}{R_1}\right](x - x_a) + \left[\frac{(y_s - y_a)}{R_1}\right](y - y_a) - \frac{z_a}{R_1}(z - z_a) \tag{3.23}$$

$$y' = \left[\frac{(y_a - y_s)}{R_2}\right](x - x_a) + \left[\frac{(x_s - x_a)}{R_2}\right](y - y_a) \tag{3.24}$$

$$z' = \left[\frac{z_a(x_s - x_a)}{R_1 R_2}\right](x - x_a) + \left[\frac{z_a(y_s - y_a)}{R_1 R_2}\right](y - y_a) + \frac{R_2}{R_1}(z - z_a). \tag{3.25}$$

3.4.1 Projection Test Points Defining Service Area Polygon

The methods of this chapter involve working with test points on the surface of the earth projected onto a plane orthogonal to the axis of the satellite antenna. Given the coordinate transformation above, finding the projection points of the test points on the earth to this plane is straightforward. A test point on the surface of the earth is given by its latitude and longitude, (θ_e, ϕ_e). The earth centered coordinates of this point are

$$\begin{aligned} z_e &= \sin\theta_e \\ y_e &= \cos\theta_e \sin\phi_e \\ x_e &= \cos\theta_e \cos\phi_e. \end{aligned} \tag{3.26}$$

These are then transformed to the aimpoint-centered coordinates, (x'_e, y'_e, z'_e), using the equations listed above. The projection of these points onto the plane orthogonal to the satellite antenna's beam axis is made by setting x'_e to zero.

Thus, from this point on, the service areas are represented by sets of points in the projection plane, i.e., the y', z' plane. These projection points will always be specified by their aimpoint-centered coordinates and denoted by (y'_p, z'_p). Note that in this system the aimpoint is at the origin. Thus given the earth-centered coordinates of the test points on the surface of the earth, the aimpoint- centered coordinates of the projections of the points can be found from

$$y'_p = \left[\frac{(y_a - y_s)}{R_2}\right](x_e - x_a) + \left[\frac{(x_s - x_a)}{R_2}\right](y_e - y_a) \tag{3.27}$$

$$z'_p = \left[\frac{z_a(x_s - x_a)}{R_1 R_2}\right](x_e - x_a) + \left[\frac{z_a(y_s - y_a)}{R_1 R_2}\right](y_e - y_a) + \frac{R_2}{R_1}(z_e - z_a). \tag{3.28}$$

The sides of the service area polygons in the y', z' plane can be characterized by the lines containing them. In the computer algorithms used for the calculations of this chapter, they are designated by their slopes and z' axis intercepts. For an n sided polygon, the line which includes the first and second vertices is designated as line 1, the line containing the second and third points is designated as line 2, and so on; the line which contains the points n and 1 is designated as line n. Two arrays store the necessary information specifying the lines; one array containing the slopes and another containing the z' axis intercepts.

The slope, m_i, of line i is found from

$$m_i = \frac{z'_{p,i+1} - z'_{p,i}}{y'_{p,i+1} - y'_{p,i}}. \tag{3.29}$$

The array element is set to -99999 as a flag when the slope is infinite. The z' axis intercept, c_i, of line i is

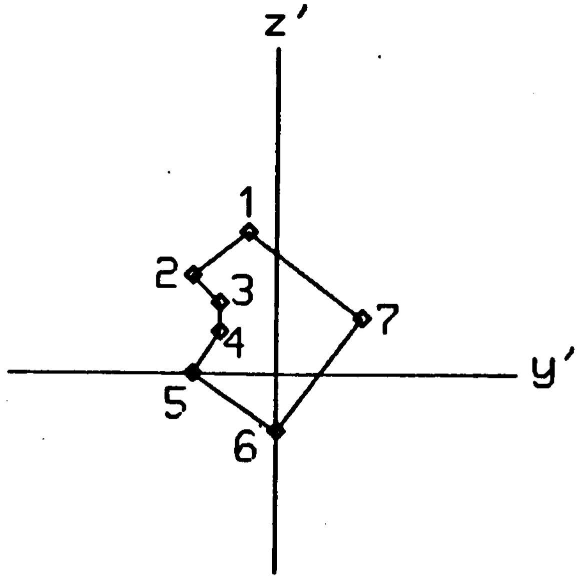

Figure 3.2: Seven-sided concave polygon to be made convex.

$$c_i = z'_{p,i} - m_i y'_{p,i}. \tag{3.30}$$

3.5 Forming a Convex Polygon

For the first of the methods discussed in this chapter, it is necessary to have a convex polygon which describes the service area. Any concavities in the service area must be eliminated by forming a new polygon with fewer sides which does not contain the points which cause the concavity. For example, Figure 3.2, shows a seven-sided polygon with a concavity. Test points 3 and 4 must be eliminated to form the five-sided convex polygon of Figure 3.3.

To generate a convex polygon the following algorithm is used. It requires checking all n points of the service area polygon at least once to see if they can be included in a convex polygon. The procedure starts with the test point designated

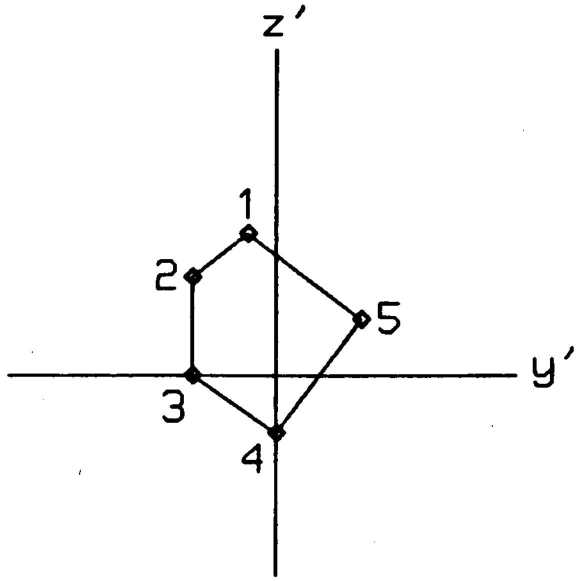

Figure 3.3: Five-sided convex polygon.

as 1. Consider the three points n, 1, and 2 as shown in Figure 3.4.

The angle θ_1 that the line segment between test point n and test point 1 makes with the positive y' axis, measured in a counterclockwise direction, is determined using the following procedure. First the terms Δz_1 and Δy_1 are calculated, where

$$\Delta z_1 = z'_{p,1} - z'_{p,n}, \tag{3.31}$$

and

$$\Delta y_1 = y'_{p,1} - y'_{p,n}. \tag{3.32}$$

If the principal value of the arctan function is defined to lie between $-90°$ and $90°$, then in order to insure that $0° \leq \theta_1 \leq 360°$, θ_1 is found as follows:

1. If $\Delta z_1 > 0$ and $\Delta y_1 > 0$ then $\theta_1 = \arctan \frac{\Delta z_1}{\Delta y_1}$
2. If $\Delta z_1 < 0$ and $\Delta y_1 > 0$ then $\theta_1 = 360° + \arctan \frac{\Delta z_1}{\Delta y_1}$

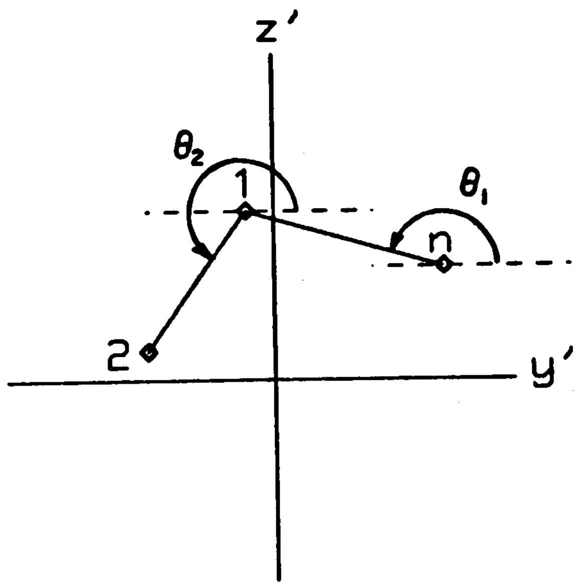

Figure 3.4: Angles used in checking whether point 1 can be included in a convex polygon.

3. If $\Delta y_1 < 0$ then $\theta_1 = 180° + \arctan \frac{\Delta z_1}{\Delta y_1}$.

The angle, θ_2, that the line segment between test points 1 and 2 makes with positive y' axis is determined in a similar manner.

Now if $\theta_1 < 180°$ and $\theta_1 < \theta_2 < \theta_1 + 180°$ then test point 1 can be included in the convex polygon. Otherwise, it must be rejected. For $\theta_1 > 180°$, it must be rejected if $\theta_1 - 180° < \theta_2 < \theta_1$. Otherwise it can be accepted.

This procedure must be carried out at least once for all n test points. Every time a test point is found to produce a concavity, a new polygon is formed which does not contain this point. Once this point has been rejected, the next lower indexed point that has been accepted must be rechecked using the new polygon. This is necessary since a concavity can include more than one test point.

3.5.1 Projection Through Center of Service Area Polygon

The first model for the directivity of the shaped-beam antenna is one that attempts to predict the shape of the loci of constant directivity based on the geometric shape of the service area. This method starts with the n sided polygon representing the service area which possibly contains some concavities. From this polygon is formed a m sided convex polygon with the procedure described in the previous section. This polygon is taken to be the locus of relative gain equal to -3 dB. This is, of course, an approximation as in practice the -3 dB contours are unlikely to be straight lines.

The heuristic argument behind this method is as follows. Consider a point (y'_0, z'_0) outside the service area polygon, at which the relative gain is to be calculated. If a line is extended from this point through the origin of the y', z' plane (the aimpoint) and across the polygon, it will intersect the polygon in two points. The distance between these points gives a measure of the "beamwidth" in this direction.

Now, for the satellite using an antenna with multiple spot beams, the service area will not be covered with a single large beam but with many smaller beams. Outside the -3 dB contour, the relative gain will decay more rapidly for the shaped-beam antenna then it would for the single-beam antenna, reflecting the smaller half-power beamwidth of the sub-beams. To reflect this in the model, the distance across the polygon representing the -3 dB contour is not used as the beamwidth in the calculations, but a fraction of this distance is used $(1/2, 1/3, 1/4, \ldots)$. For the calculations of this manuscript, 1/3 has been used. The relative gain in the exterior of the service area polygon is calculated by assuming that it falls off from -3 dB as would a single beam with a beamwidth equal to 1/3 the distance across the polygon, measured in the y', z' plane. This is illustrated in Figure 3.5.

It is important with this method to place a constraint on the minimum beamwidth dimension that can be permitted. Otherwise the relative gain could decay arbitrarily fast outside a service area that is narrow in one dimension. In the computer program used for the calculations of this report, the minimum allowable beamwidth is an input parameter.

Note that this method does not provide a model that has a consistent beamwidth size as do the other methods explained in this chapter. The value of the beamwidth used in the calculations will vary considerably depending on the location of the point at which the relative gain is being calculated. One can visualize the service area being covered with many sub-beams. The "axial ratio" of the sub-beams will be approximately equal to the ratio of the longest dimension across the service area polygon to the smallest dimension.

The following procedure is used to calculate the gain at the point (y'_0, z'_0) which is outside the service area polygon.

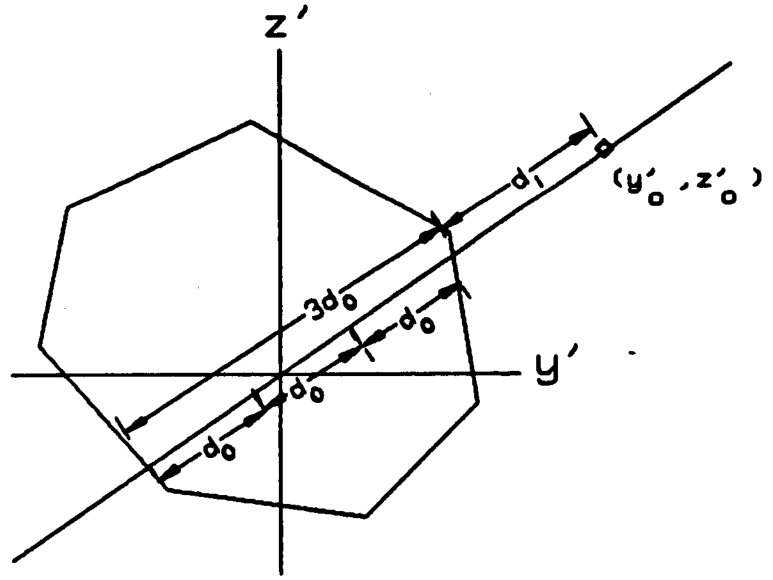

Figure 3.5: Geometry of the "Projection Through Center" method.

1. Find the slope, m_0, of the line, l_0, passing through the origin and (y'_0, z'_0); this is given by $m_0 = \frac{z'_0}{y'_0}$.

2. For each side i of the polygon, find if there is an intersection with l_0 using the following procedure.

   (a) First find the point of intersection, $(y'_{k,i}, z'_{k,i})$, of l_0 and the line l_i which contains side i of the polygon using the following relationships. Setting the z' coordinates equal yields

   $$y'_{k,i}m_i + c_i = m_0 y'_{k,i}. \tag{3.33}$$

   Thus, the desired y' coordinate of intersection is found from

   $$y'_{k,i} = \frac{c_i}{m_0 - m_i}. \tag{3.34}$$

   The z' coordinate of intersection is found from

   $$z'_{k,i} = m_i y'_{k,i} + c_i. \tag{3.35}$$

   (b) Check to see if the point $(y'_{k,i}, z'_{k,i})$ is on the line segment which is side i of the polygon.

3. After this has been done for all sides of the polygon, there will be two points of intersection. Compute the distance between the point being tested and these points. Label the closest point, (y'_f, z'_f), and the farthest point, (y'_r, z'_r).

4. Compute the "beamwidth", d_0, by computing the distance across the polygon and taking 1/3 of this distance. Thus, d_0 is found from

   $$d_0 = \frac{1}{3}\sqrt{(y'_r - y'_f)^2 + (z'_r - z'_f)^2}. \tag{3.36}$$

5. Compare d_0 to the value of the minimum permissible beamwidth. If d_0 is less than the minimum beamwidth, then set d_0 equal to the minimum beamwidth.

6. Compute the distance, d_1 from the point being tested to the polygon from

$$d_1 = \sqrt{(y_0' - y_f')^2 + (z_0' - z_f')^2}. \tag{3.37}$$

7. Calculate the relative gain below maximum by using one of the two gain patterns given below.

The following two patterns are used for both this method and the "uniform rolloff" method to be discussed. The first is basically the FSS elliptical pattern described in Chapter 2. The quadratic portion of this curve has been modified slightly by adding an additional factor of -3 dB so that the relative gain falls off from -3 dB at the borders of the service area polygon.

$$\begin{aligned} D\left(\tfrac{d_1}{d_0}\right)(dB) &= -3 - 12\left(\tfrac{d_1}{d_0}\right)^2 && 0 \le \tfrac{d_1}{d_0} \le 1.19 \\ &= -20 && 1.19 < \tfrac{d_1}{d_0} \le 3.15 \\ &= -7.5 - 25\log\left(\tfrac{d_1}{d_0}\right) && \tfrac{d_1}{d_0} > 3.15. \end{aligned} \tag{3.38}$$

The second pattern is a modification of a BSS satellite transmitting pattern from the WARC-85 Conference [21, p. 102]. The equations describing the envelope are

$$\begin{aligned} D\left(\tfrac{d_1}{d_0}\right)(dB) &= -3 - 12\left(\tfrac{d_1}{d_0}\right)^2 && 0 \le \tfrac{d_1}{d_0} \le 1.5 \\ &= -30 && 1.5 < \tfrac{d_1}{d_0} \le 3.15 \\ &= -17.5 - 25\log\left(\tfrac{d_1}{d_0}\right) && \tfrac{d_1}{d_0} > 3.15. \end{aligned} \tag{3.39}$$

Notice that the two patterns are identical except the level of the flat portion of the curve in the sidelobes of the antenna. Thus, these two patterns will produce identical results for values of the relative gain of -20 dB or greater.

3.5.2 Uniform Rolloff From the Boundary of the Service Area Polygon.

This method attempts to model the effects of shaped beams by means of a uniform rate of falloff of the relative gain outside the service area polygon. With this method, it is assumed that the service area has been covered with circular sub-beams of a uniform diameter. The beamwidth size used in the calculations is considered fixed at the specified beamwidth of the individual sub-beams. The locus of relative gain equal to -3 dB is taken to be the polygon defining the service area. As in the previous method, this assumption is contrary to fact as the -3 dB contour will most likely not be a set of straight lines following the sides of the service area. A choice of polygons is available; the original polygon which may contain some concavities can be used as can the convex polygon used in the first method. The second choice is a more conservative selection. The relative gain below maximum outside the service area polygon is a function of the closest distance from the point being tested to the polygon.

Given a test point outside the service area polygon, the minimum distance to the polygon is determined as follows.

1. For each side, i, of the polygon, find the shortest distance between it and the point being tested using the following procedure.

    (a) Find the perpendicular from the point being tested to the line containing the side of the polygon. There are three cases:

        i. The side of the polygon is vertical in the y', z' plane. The equation of line l_i, which contains side i is $y = K$, for some constant K. The point of the intersection of the perpendicular with the side of the

polygon is (K, z'_0)

ii. The side of the polygon is horizontal in the y', z' plane. The equation of line i is $z = c_i$. The point of intersection of the perpendicular with side i is (y'_0, c_i).

iii. The side is contained by l_i which has finite, non-zero slope. The point of intersection, $(y'_{k,i}, z'_{k,i})$ of the perpendicular with the side of the polygon is found from

$$y'_k = \frac{z'_0 + (1/m_i)y'_0 - c_i}{m_i + 1/m_i}, \tag{3.40}$$

and

$$z'_k = \frac{(z'_0 - c_i)m_i + y'_0}{(m_i + 1/m_i)} + c_i. \tag{3.41}$$

(b) Determine whether the point of intersection of line i and the perpendicular to it containing the point being tested is on the line segment which is side i of the polygon. If it is, it is the closest point to the polygon. If not, then the closest point is the closer of the two endpoints of side i.

2. Given a set of the shortest distances to each side of the polygon, take the minimum of these as the shortest distance from the point being tested to the polygon. Label this shortest distance, d_1.

Once the shortest distance to the service area polygon is found, the relative gain can be calculated. For this method, the size of the beamwidth, d_0, (i.e., the common diameter of the circular sub-beams) is an input parameter. The beamwidth is specified in terms of the chord measured in the y', z' plane rather than an angle measured at the satellite. The relative gain is calculated from the ratio of d_1 to d_0 using either of the two patterns listed in the previous section, i.e., Equation (3.35) or (3.36).

3.5.3 Method Using N Circular Sub-beams

The final method of generating shaped-beam contours is by covering the service area polygon in the plane orthogonal to the beam axis with circular sub-beams of uniform radius. Given the locations of the centers of the sub-beams, the relative gain at a given point can be estimated by the superposition of the fields from each at that point. This method has been used to substitute for the lack of data on real shaped-beam antennas. It simulates the sort of process that might be used in designing a shaped-beam antenna with multiple feeds.

This sort of method would probably not be feasible for an actual program to determine required separation values for a large number of satellites due to its subjective nature and the length of time involved in its application. The diameter of the circular sub-beams is selected to allow a sensible number of beams to cover the service area. The placement of the individual beams is then done using a graphics terminal to produce an arrangement that seems reasonable. After an arrangement is produced, gain contours for that arrangement are calculated using the method described in the next section. If the contours produced are not satisfying, the placement of the sub-beams is changed slightly and the contours recalculated. The drawing work is done using the Teknicad graphics package available at the OSU Electro-Science Lab [22].

Once the location of the sub-beams in the plane orthogonal to the beam axis is determined, the gain contours are determined using the superposition of idealized voltage patterns for each sub-beam. The two relative gain patterns used are essentially the same patterns described earlier without the modifications for use with polygonal -3 dB contours. The first is the FSS elliptical pattern from Chapter 2.

The equations describing the envelope of this pattern are

$$\begin{aligned} D(\tfrac{d_1}{d_0})(dB) &= -12(\tfrac{d_1}{d_0})^2 && 0 \le \tfrac{d_1}{d_0} \le 1.29 \\ &= -20 && 1.29 < \tfrac{d_1}{d_0} \le 3.15 \\ &= -7.5 - 25\log(\tfrac{d_1}{d_0}) && \tfrac{d_1}{d_0} > 3.15. \end{aligned} \tag{3.42}$$

The second is the satellite transmitting antenna envelope listed earlier which comes from the WARC-85 conference. The equations describing the envelope, in dB, are

$$\begin{aligned} D(\tfrac{d_1}{d_0})(dB) &= -12(\tfrac{d_1}{d_0})^2 && 0 \le \tfrac{d_1}{d_0} \le 1.58 \\ &= -30 && 1.58 < \tfrac{d_1}{d_0} \le 3.15 \\ &= -17.5 - 25\log(\tfrac{d_1}{d_0}) && \tfrac{d_1}{d_0} > 3.15. \end{aligned} \tag{3.43}$$

These two patterns are converted to the following two voltage patterns, listed in terms of ratios. The first corresponds to the FSS envelope,

$$\begin{aligned} V(\tfrac{\alpha}{\alpha_0}) &= 10^{-0.6(\frac{\alpha}{\alpha_0})^2} && 0 \le \tfrac{\alpha}{\alpha_0} \le 1.29 \\ &= 0.1 && 1.29 < \tfrac{\alpha}{\alpha_0} \le 3.15 \\ &= 0.41965(\tfrac{\alpha}{\alpha_0})^{-1.25} && 3.15 < \tfrac{\alpha}{\alpha_0}. \end{aligned} \tag{3.44}$$

The second corresponds to the BSS envelope,

$$\begin{aligned} V(\tfrac{\alpha}{\alpha_0}) &= 10^{-0.6(\frac{\alpha}{\alpha_0})^2} && 0 \le \tfrac{\alpha}{\alpha_0} \le 1.58 \\ &= 0.03162 && 1.58 < \tfrac{\alpha}{\alpha_0} \le 3.15 \\ &= 0.13269(\tfrac{\alpha}{\alpha_0})^{-1.25} && 3.15 < \tfrac{\alpha}{\alpha_0}. \end{aligned} \tag{3.45}$$

Figure 3.6 shows plots of these voltage patterns for comparison. The two are identical out to the flat portion of the envelope in the sidelobes.

The first step in the process is to calculate a value for the gain at the aimpoint, which is the origin of the y', z' plane. The aimpoint is assumed to be the point of maximum gain as a simplifying assumption. In general, a maximum gain will not occur precisely at the aimpoint but somewhere close to it in the interior of the service area. The distance from the aimpoint to the center location of each sub-beam is found; from this is determined the contribution from that sub-beam. The total voltage is just the sum of the contributions from each sub-beam,

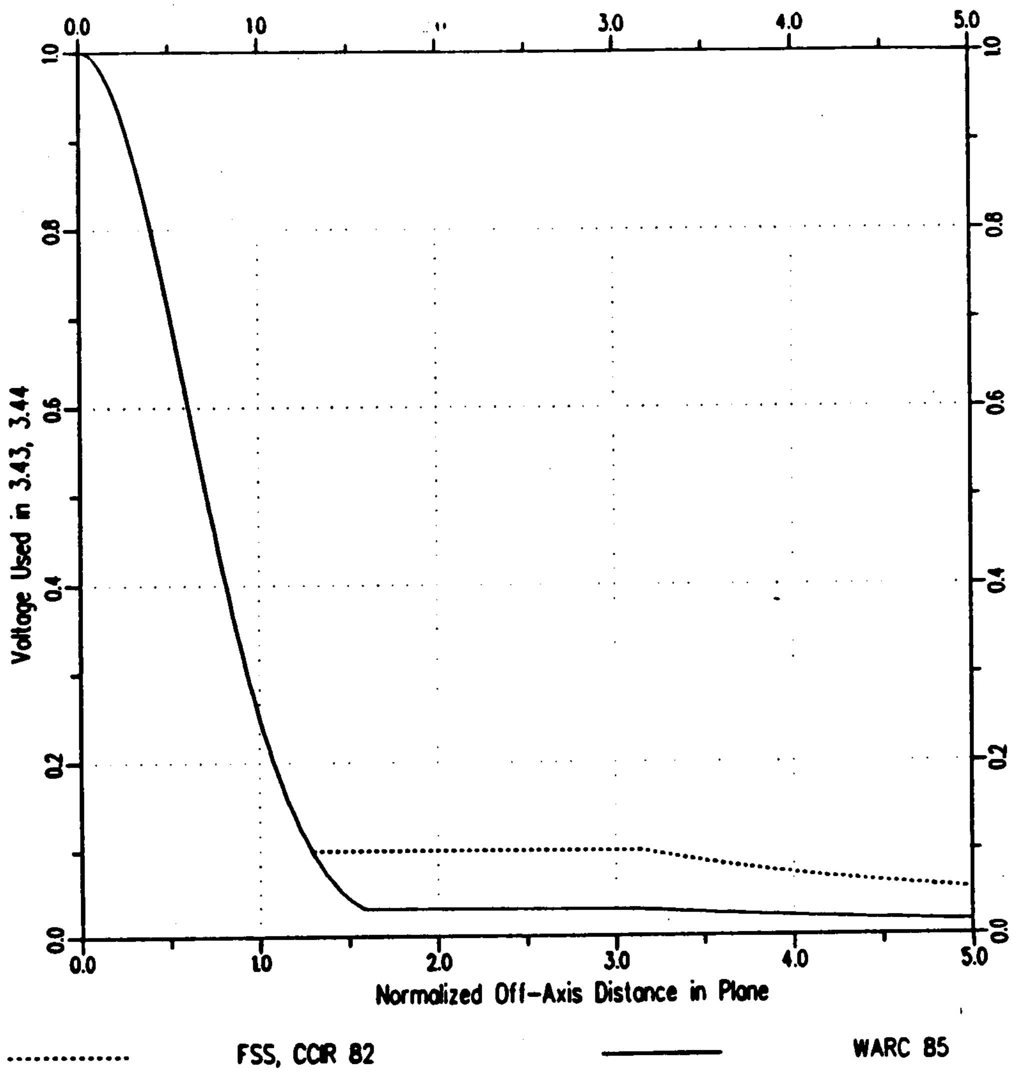

Figure 3.6: Comparison of the two voltage patterns used in the "N-beam" method.

$$V_t = \sum_{i=1}^{m} V_i. \tag{3.46}$$

The value in dB, of the square of this quantity, denoted by G is then found from

$$G(dB) = 20\log(V_t) = 20\log\left(\sum_{i=1}^{m} V_i\right) \tag{3.47}$$

This value is saved to be used as the maximum gain value in the succeeding calculations.

To calculate the relative gain at a point other than the aimpoint, the same process is used. The distance from the point being tested to the center location of each circular sub-beam is calculated and the voltage contribution from the sub-beam is determined. The total voltge is the sum of the contributions from all of the sub-beams. The square of this quantity, in dB, is then found. The relative gain below maximum is then found by subtracting the value of G found earlier from this value.

3.6 Gain Contour Plots

3.6.1 Introduction

The following section contains plots of the gain contours which result from these procedures. These plots show a view from the satellite of the y', z' plane orthogonal to the axis of the satellite antenna. The projections, in this plane, of the test points defining the service area are marked in these plots by asterisks. The plots are generated as follows.

A ray is extended from the origin at a given angle, θ, and the distance along this ray that an observer must move for the relative gain of the satellite antenna to be at a specified level is determined. This is repeated for all values of θ from 0

degrees to 358 degrees in 2 degree increments, for all specified values of the relative gain. In this way, the loci of constant relative gain can be determined for all values of relative gain desired. In the plots of this chapter, the -3 dB, -6 dB, -12 dB, and -18 dB contours are shown.

For the elliptical pattern and elliptical half-power pattern, the distance from the origin that must be moved can be calculated directly by the following algorithm. The geometry of the minimum ellipse in the y', z' plane is shown in Figure 3.7. Note that the orientation angle, is defined as the angle the major axis makes with the y' axis.

First, the range from the satellite to its aimpoint must be calculated. This is trivial if the satellite is described by its aimpoint centered coordinates, $(x'_s, 0, 0)$, as it is just x'_s. Next, the lengths of the major and minor axes in the y', z' plane are determined. This must be done because these dimensions are specified in terms of the angles subtended by the ellipse as seen from the satellite. Let the angular major axis be specified as ψ_a, and the minor axis as ψ_b. The length of the chord $\overline{OA}$ in the y', z' plane is

$$\overline{OA} = x'_s \tan(\psi_a/2). \tag{3.48}$$

The major axis, a, is twice this length: $a = 2\overline{OA}$. The length of the chord, $\overline{OB}$, in the y', z' plane is

$$\overline{OB} = x'_s \tan(\psi_b/2). \tag{3.49}$$

The length of the minor axis, b, is $b = 2\overline{OB}$. The beamwidth, c, seen by the observer at point R can now be calculated from

$$c = \frac{a}{\sqrt{\cos^2(\theta - \sigma) + (a/b)^2 \sin^2(\theta - \sigma)}}, \tag{3.50}$$

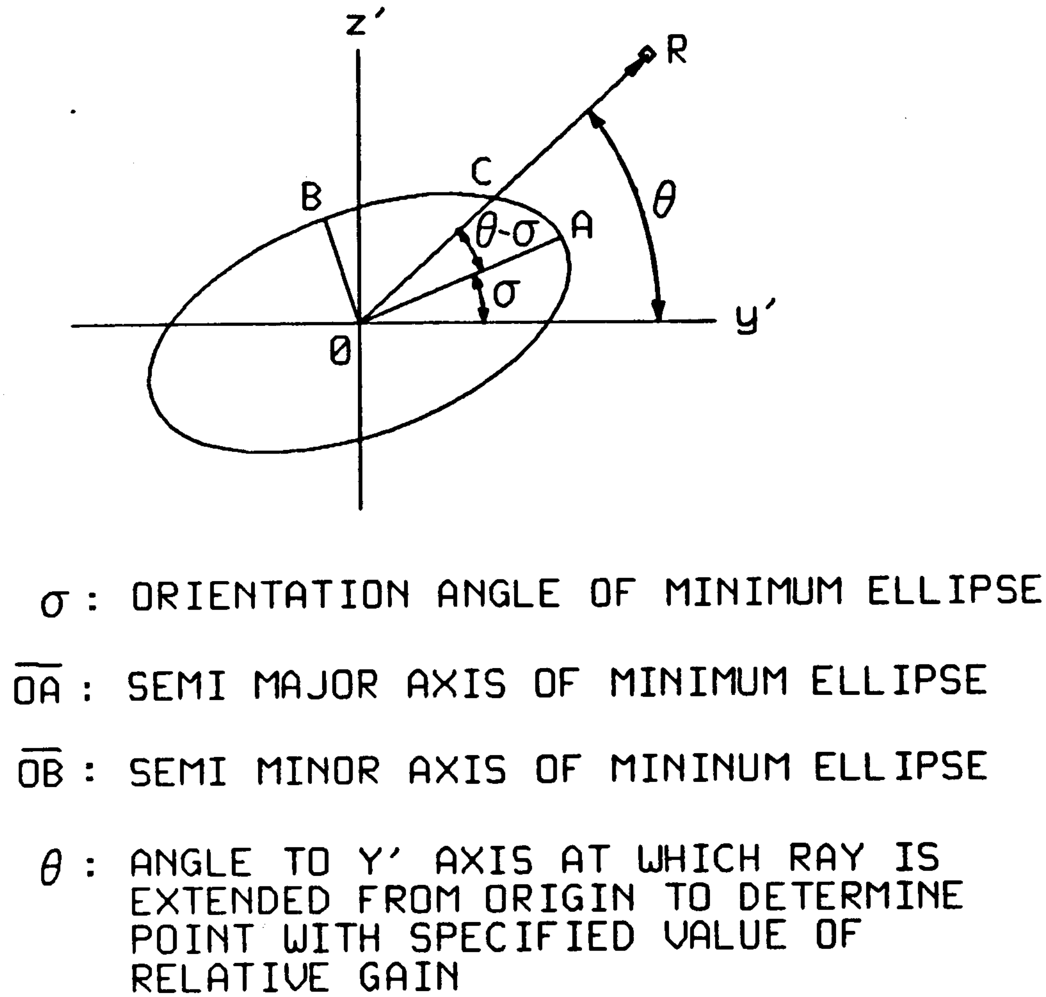

Figure 3.7: Configuration of minimum ellipse in y', z' plane.

as this is twice the length of the chord $\overline{OC}$. The angular beamwidth, ψ_c, seen at the satellite is

$$\psi_c = 2\arctan(\frac{c}{2x'_s}). \tag{3.51}$$

Once the beamwidth is found, the off axis angle needed to produce the desired relative gain can be calculated. If the standard FSS elliptical pattern, i.e., Equation (2.9), is being used the equation is

$$\psi = \psi_0\sqrt{-\frac{D(\psi,\psi_0)}{12}}. \tag{3.52}$$

For the "fast rolloff" elliptical half-power pattern, i.e. Equation (3.2) is used, the equation is

$$\psi = \psi_0\left[\frac{\sqrt{-D(\psi,\psi_0)/18.75}}{\psi_0} + \frac{1}{2}\left(1 - \frac{0.8}{\psi_0}\right)\right]. \tag{3.53}$$

Given ψ, the desired distance $\overline{OR}$ is found from

$$\overline{OR} = x'_s \tan\psi. \tag{3.54}$$

For the method of projection through the center, the distance on the ray between the two sides of the polygon that it intersects is calculated, and this information is used to calculate the required distance along the ray that must be moved to get the desired gain. The calculation proceeds as described in Section 3.3.4, using the pattern in equation 3.36

For the method which involves calculating the gain based on the superposition of the fields from the individual sub-beams, an iterative procedure is used to find the required distance out along this ray, with the gain calculated in each iteration as explained in section 3.3.6. The pattern used is that described by equations 3.40 and 3.42 .

Likewise, for the method of uniform falloff from the edge of the polygon, an iterative procedure is used with the gain calculated at each iteration as explained in section 3.3.5 . The pattern used is that described by equation 3.36 .

3.6.2 Chilean Satellite at $-50°$ W

The first set of plots shows the results of using the models described in this chapter for a Chilean satellite at $-50°$ W . Figure 3.8 shows the gain contours which result when the FSS elliptical pattern described in Chapter 2 is used. Figure 3.9 (note the change of scale) shows the improvement in these contours when the "fast rolloff" elliptical half-power pattern defined by Equation (3.2) is used. The reduction in the amount of interference power transmitted to areas outside the service area is dramatic.

Three different designs which have been developed using circular sub-beams and the gain contours which result from these designs are displayed in the next six plots. Figure 3.10 shows a three beam design with a beam radius of $0.11R_e$. Figure 3.11 shows the gain contours which result from this design. Figure 3.12 shows a five beam design with a beam radius of $0.065R_e$ and Figure 3.13 shows the gain contours which result. Figure 3.14 shows an 8 beam design with a beam radius of $0.045R_e$ while Figure 3.15 shows the resulting contours. These plots indicate the advantages of using smaller sized sub-beams. As the beam size decreases, the -3 dB contour more closely follows the outline of the service area and the gain decays faster outside the service area.

Figures 3.16 through 3.19 show the results of using the uniform rolloff method. Figure 3.16 is the result of using the uniform rolloff pattern from the concave service area polygon with an assumed beam radius of $0.045R_e$. Figure 3.17 is the same plot

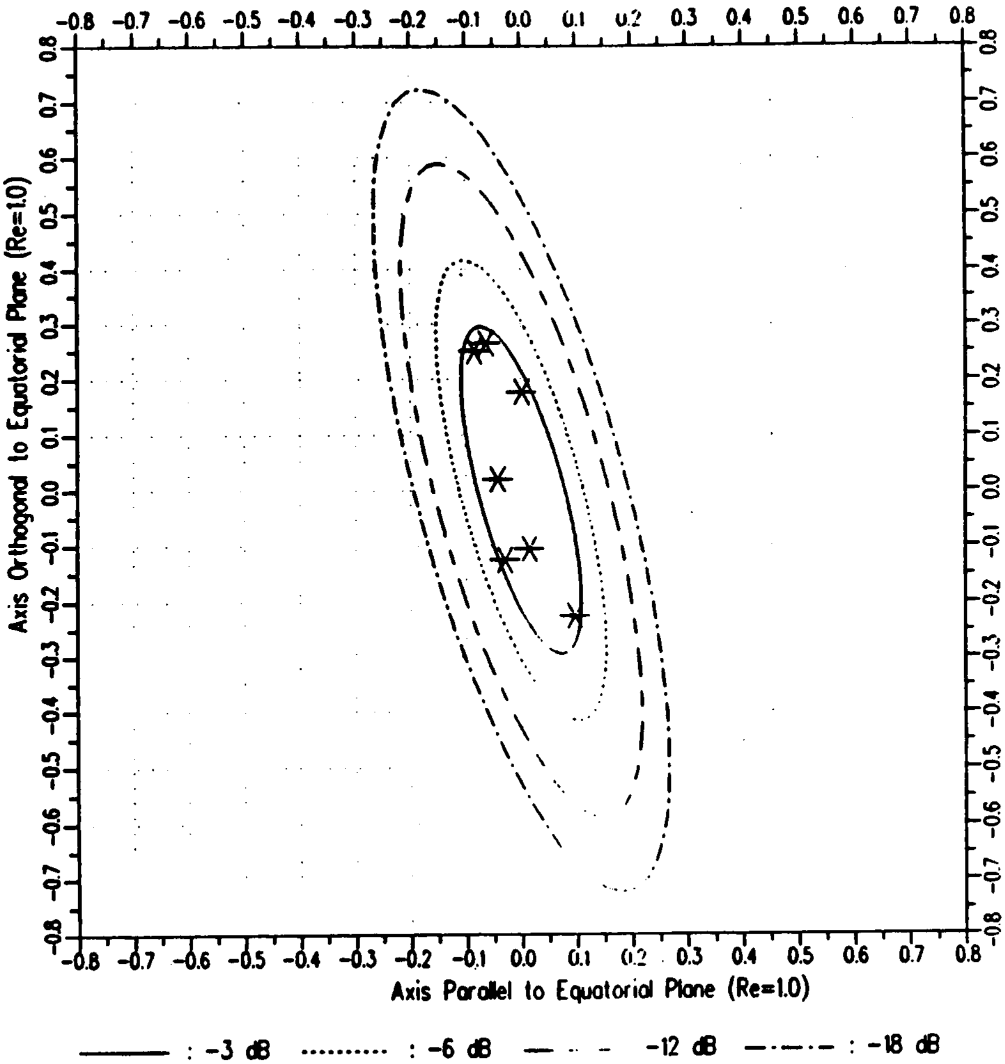

Figure 3.8: Gain contours for a Chilean satellite at $-50°$ W using the FSS elliptical pattern.

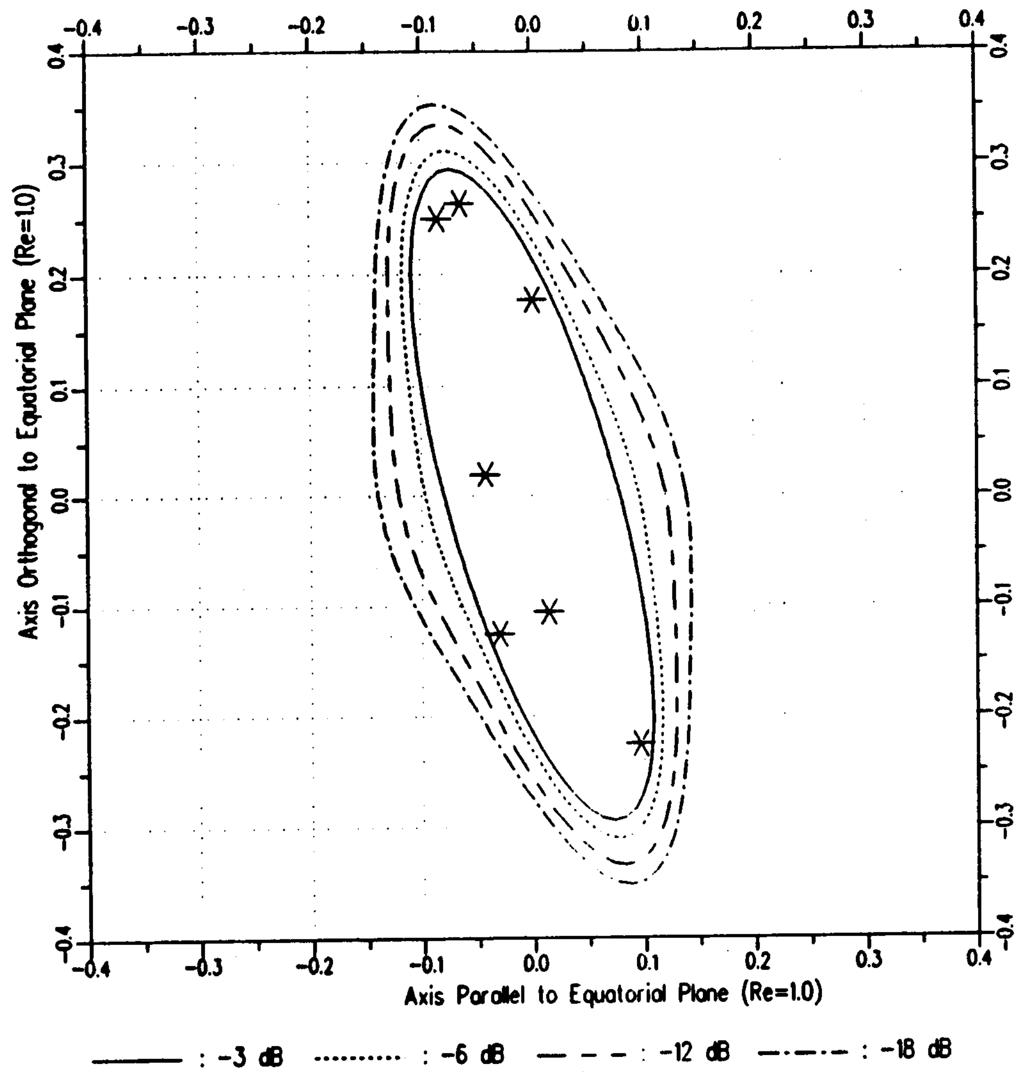

Figure 3.9: Gain contours for a Chilean satellite at $-50°$ W using the "fast rolloff" elliptical half-power pattern.

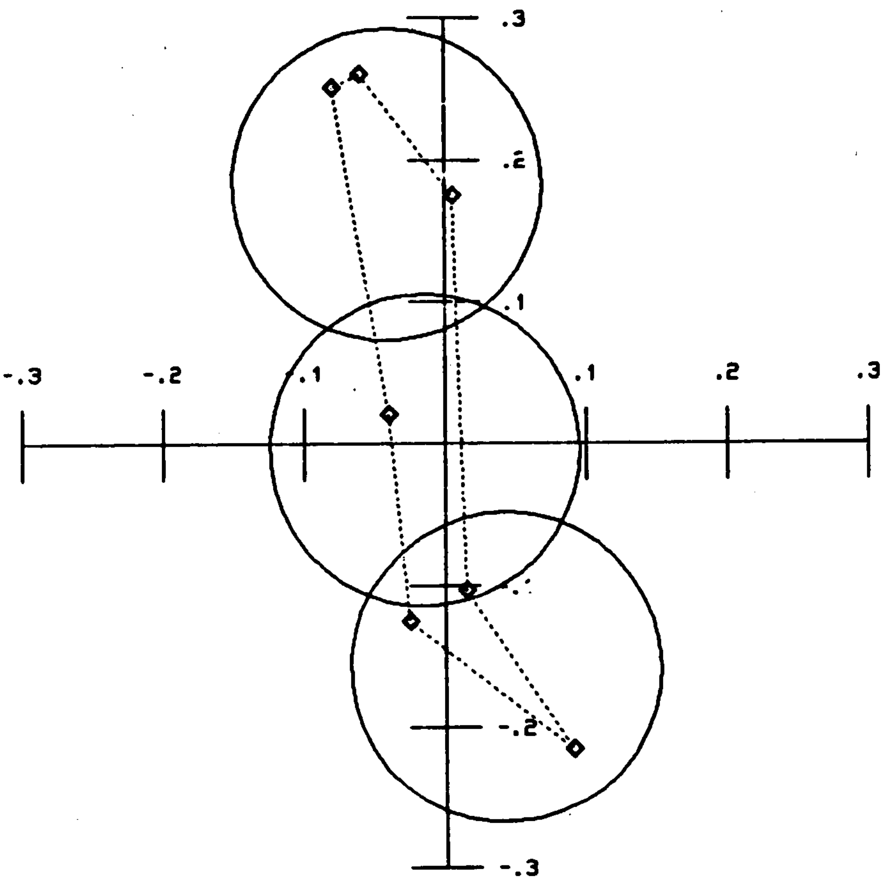

Figure 3.10: Three-beam design for a Chilean satellite at $-50°$ W using a beam radius of $.11R_e$.

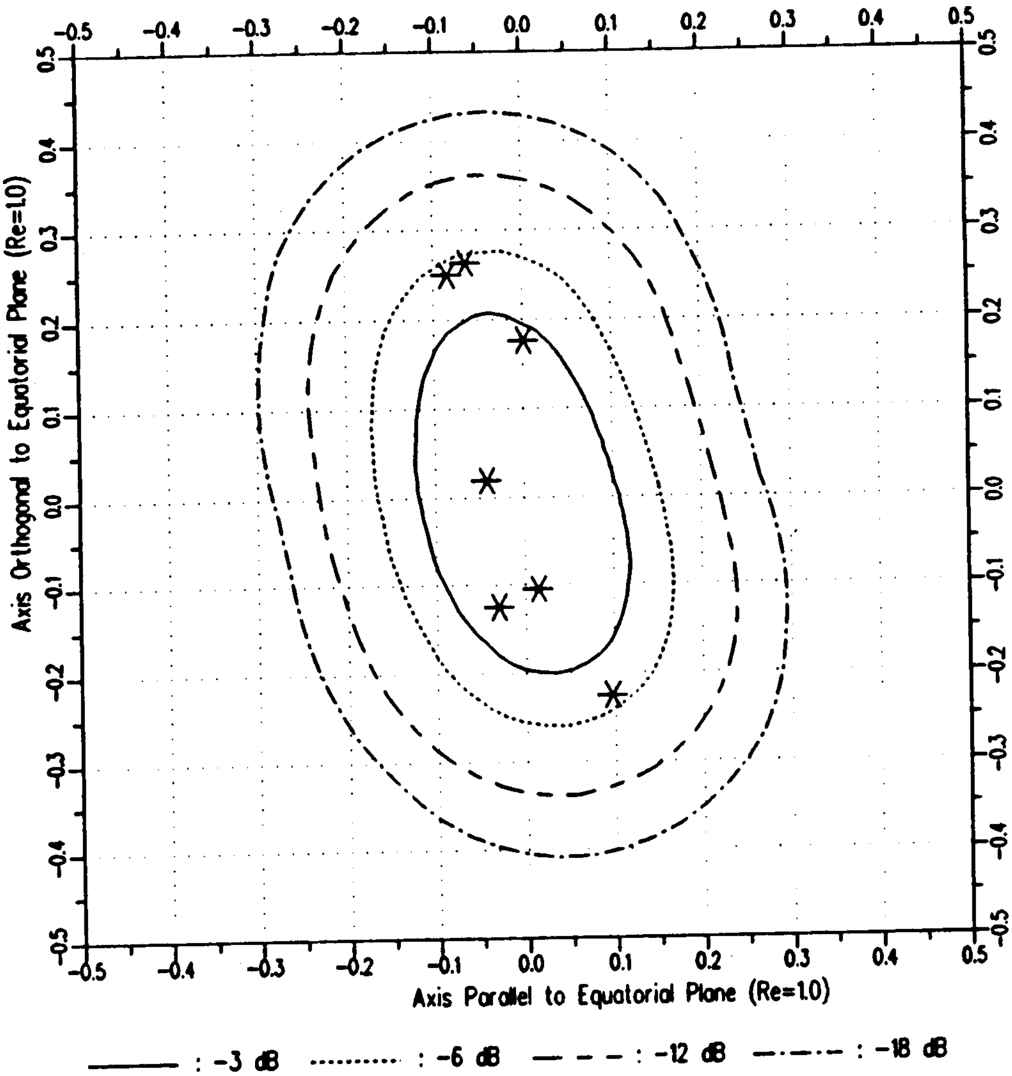

Figure 3.11: Gain contours for a Chilean satellite at $-50°$ W using the three-beam design with a $.11R_e$ beam radius.

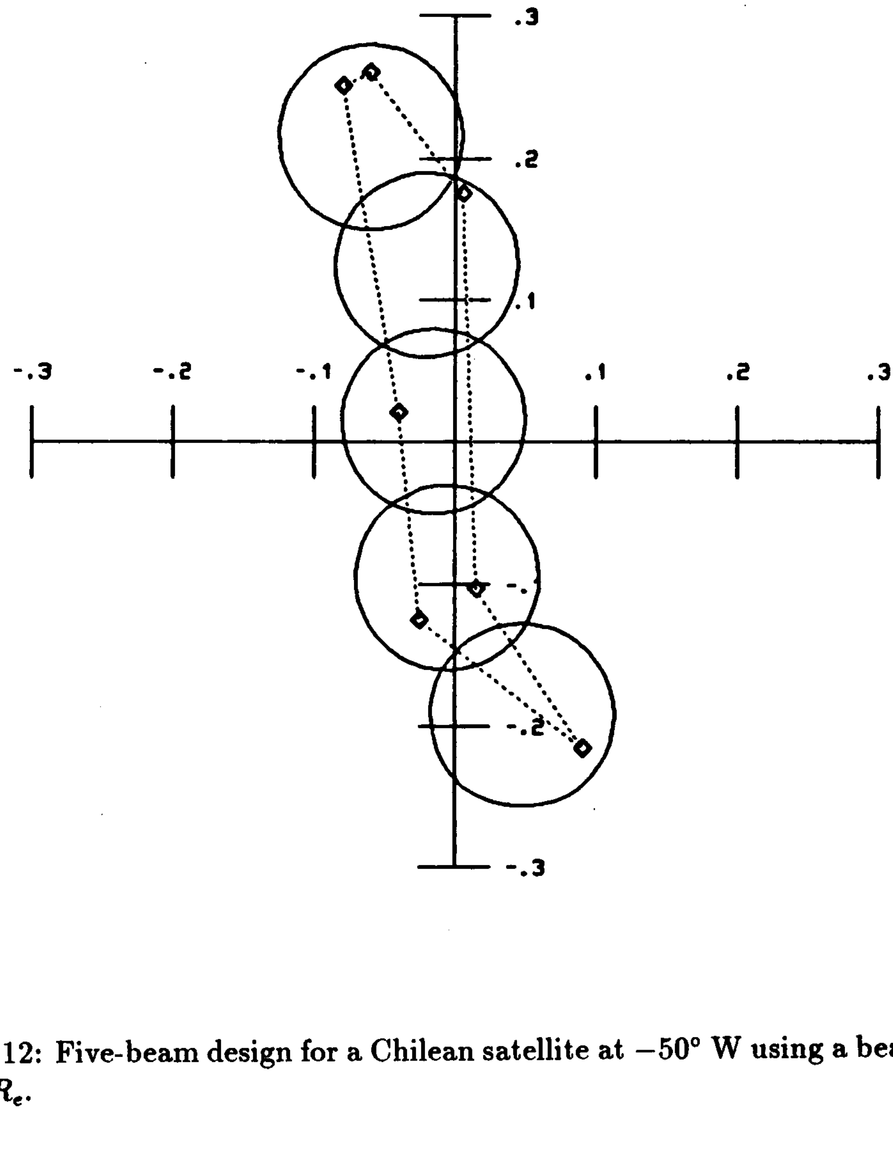

Figure 3.12: Five-beam design for a Chilean satellite at $-50°$ W using a beam radius of $0.065R_e$.

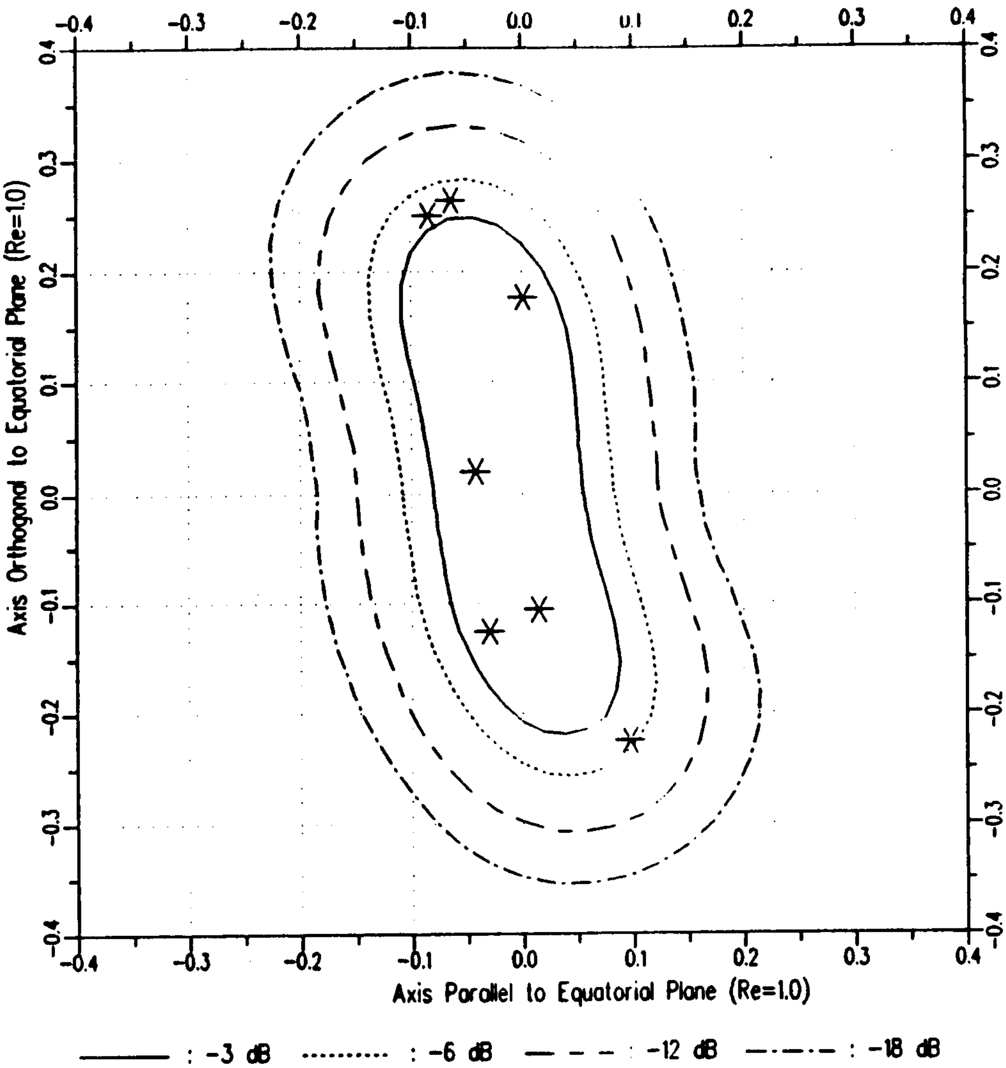

Figure 3.13: Gain contours for a Chilean satellite at $-50°$ W using the five-beam design with a beam radius of $0.065R_e$.

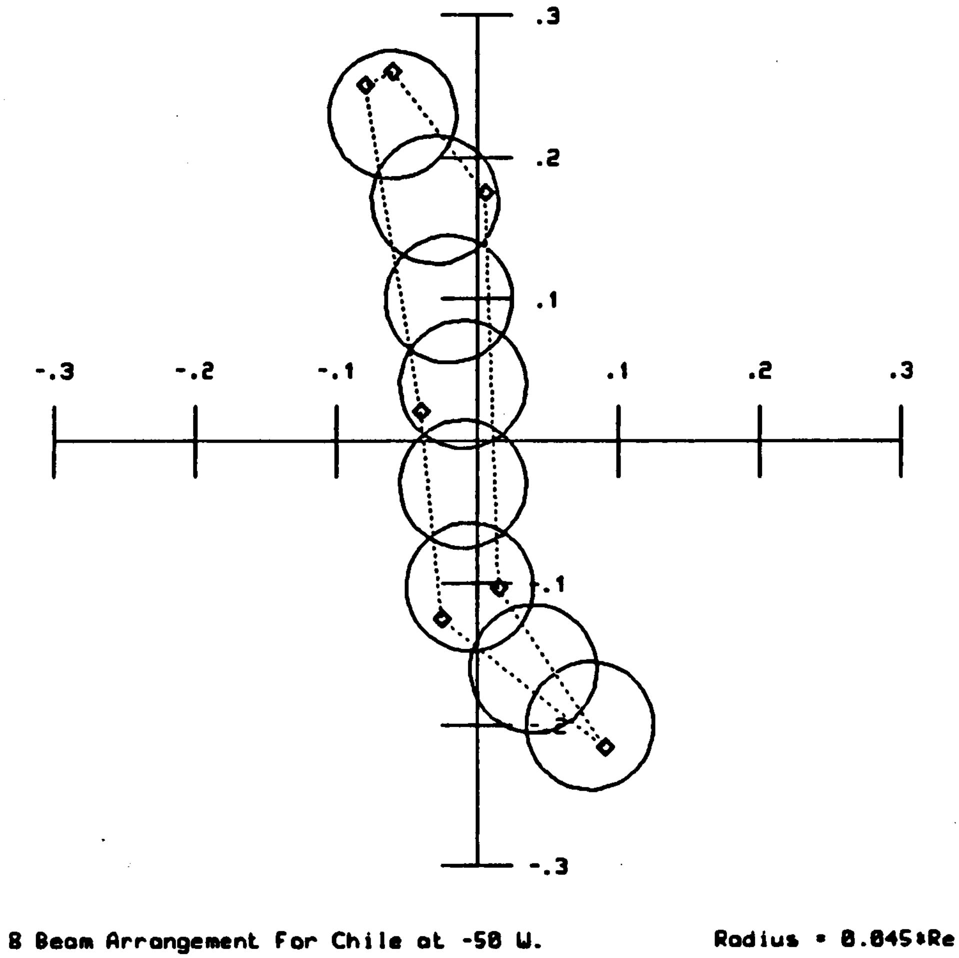

Figure 3.14: Eight-beam design for a Chilean satellite at $-50°$ W using a beam radius of $0.045R_e$.

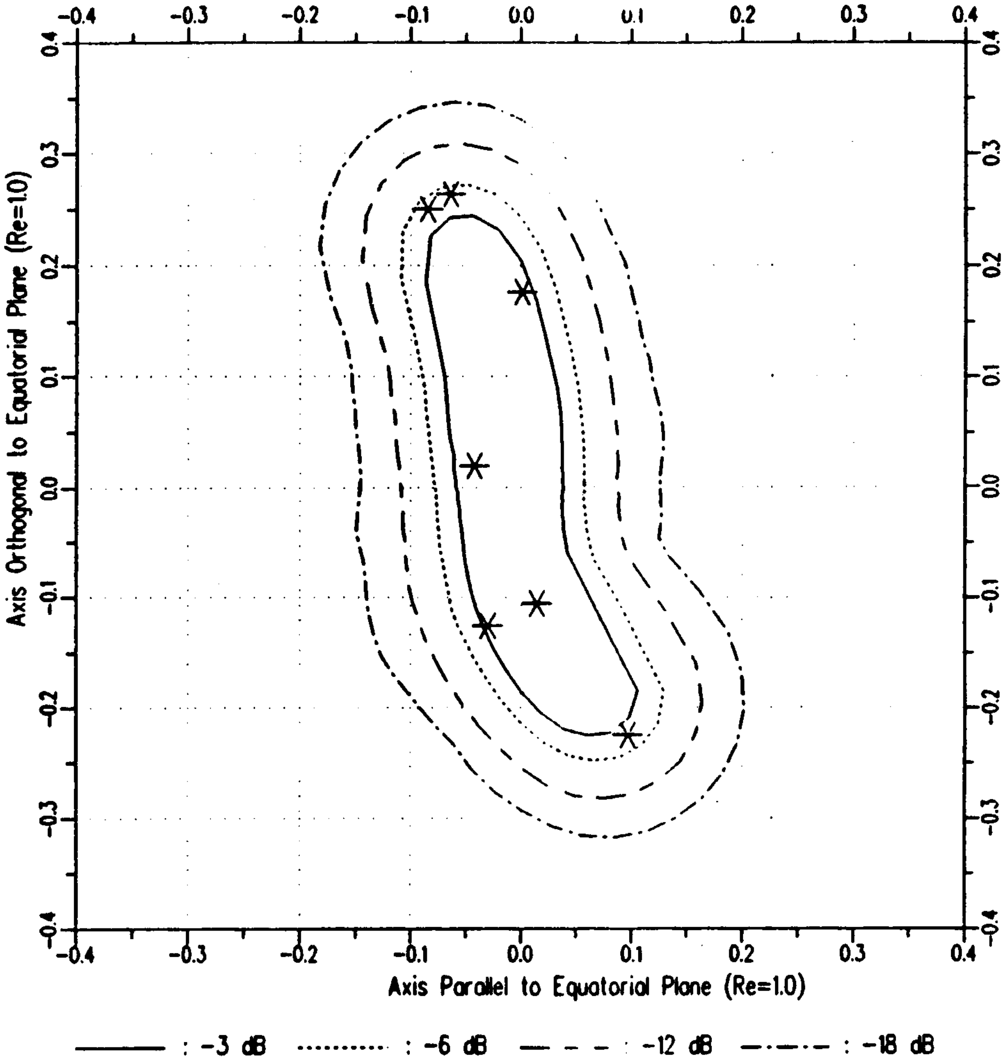

Figure 3.15: Gain contours for a Chilean satellite at $-50°$ W using the eight-beam design with a beam radius of $0.045R_e$.

with the assumed beam radius changed to $0.065R_e$. Figure 3.18 shows the results of assuming that the uniform rolloff occurs from a convex polygon with an assumed beam radius of $0.045R_e$. Figure 3.19 is the same plot with the assumed beam radius equal to $0.065R_e$.

Since the uniform rolloff method and the n-beam method are both based on the assumption of coverage with uniform circular beams, the question arises as to whether or not the contours which result from these two methods are similar. Figure 3.20 shows an overlay plot of the contours which result from the uniform rolloff method with an assumed beam radius of $0.045R_e$ and those resulting from the 8 beam design of Figure 3.14. Figure 3.21 shows an overlay of the contours using the uniform rolloff method from the concave polygon with an assumed beam radius of $0.065R_e$ and the 5 beam design of Figure 3.12. The overlay plots show the sets of -6, -12 and -18 dB contours for both methods. The uniform rolloff patterns using the concave polygon are, to some extent, approximations of the n circular sub-beam designs. The are certainly not identical, however, and there is one notable difference in the uniform rolloff patterns and the n circular sub-beams patterns. The gain in the uniform rolloff pattern decays as a quadratic function of the normalized off axis angle. Thus there is a wider spacing between the -3 dB and -6 dB contours than between the -6 dB and -12 dB contours. The opposite effect occurs when the n circular sub-beam patterns are calculated using the assumptions of section 3.3.6 .

The next three figures show the results of using the method of taking a projection through the center. Three different values of the minimum tolerable beamwidth are tried. Figure 3.22 shows the contours when the minimum beamwidth is $0.05R_e$. Figure 3.23 shows the same thing with the beamwidth changed to $0.09R_e$, while Figure 3.24 shows the plot with a beamwidth of $0.13R_e$. As the minimum tolerable

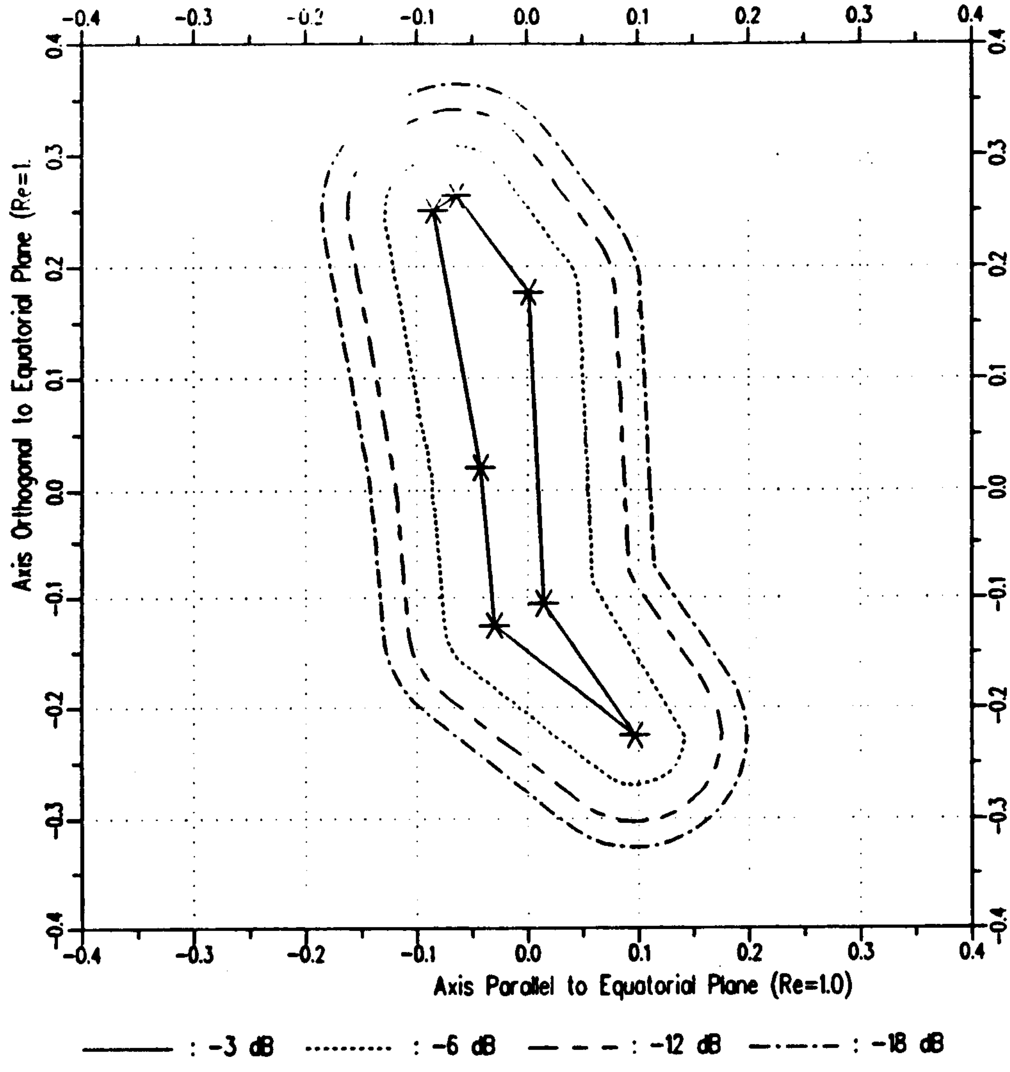

Figure 3.16: Gain contours for a Chilean satellite at $-50°$ W using the uniform rolloff method from a concave polygon with an assumed beam radius of $0.045R_e$.

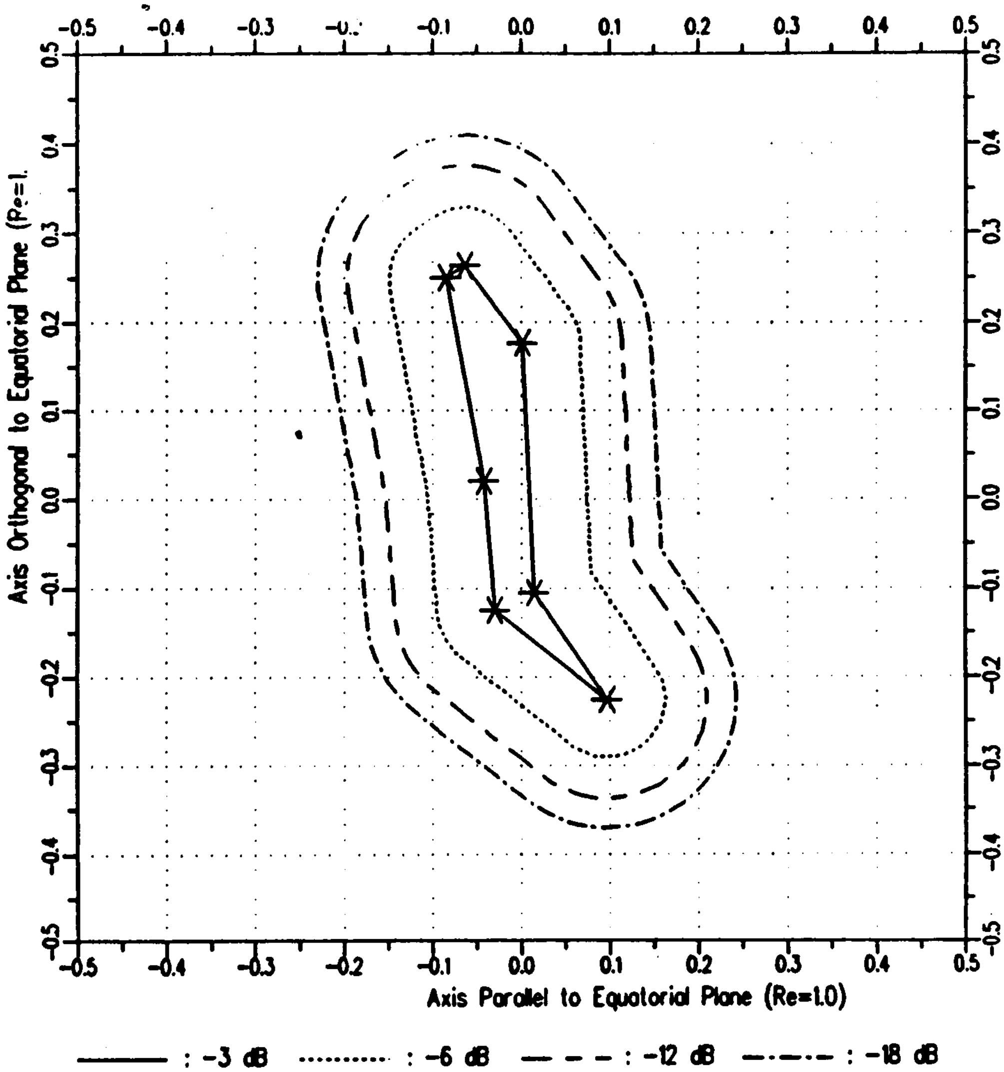

Figure 3.17: Gain contours for a Chilean satellite at $-50°$ W using the uniform rolloff method from a concave polygon with an assumed beam radius of $0.065R_e$.

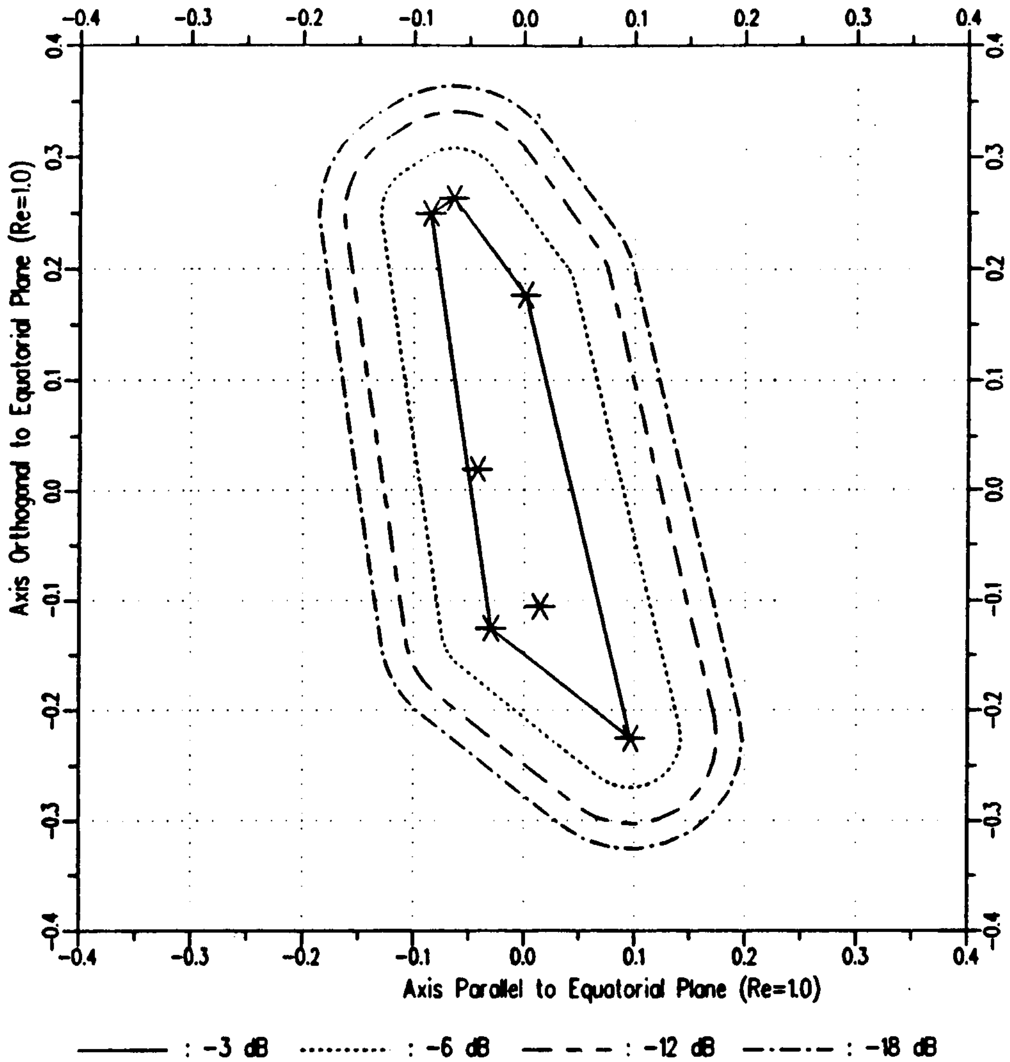

Figure 3.18: Gain contours for a Chilean satellite at $-50°$ W using the uniform rolloff method from a convex polygon with an assumed beam radius of $0.045R_e$.

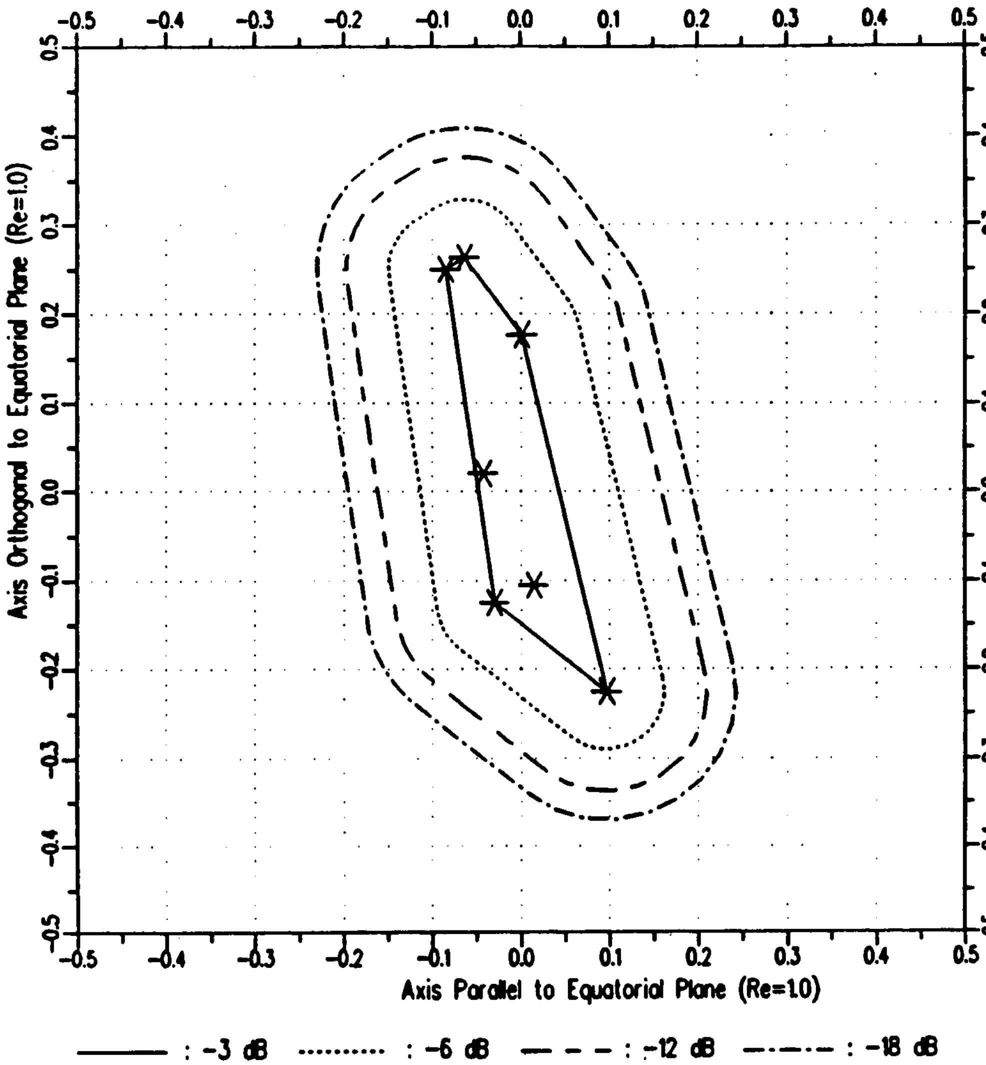

Figure 3.19: Gain contours for a Chilean satellite at $-50°$ W using the uniform rolloff method from a convex polygon with an assumed beam radius of $0.065R_e$.

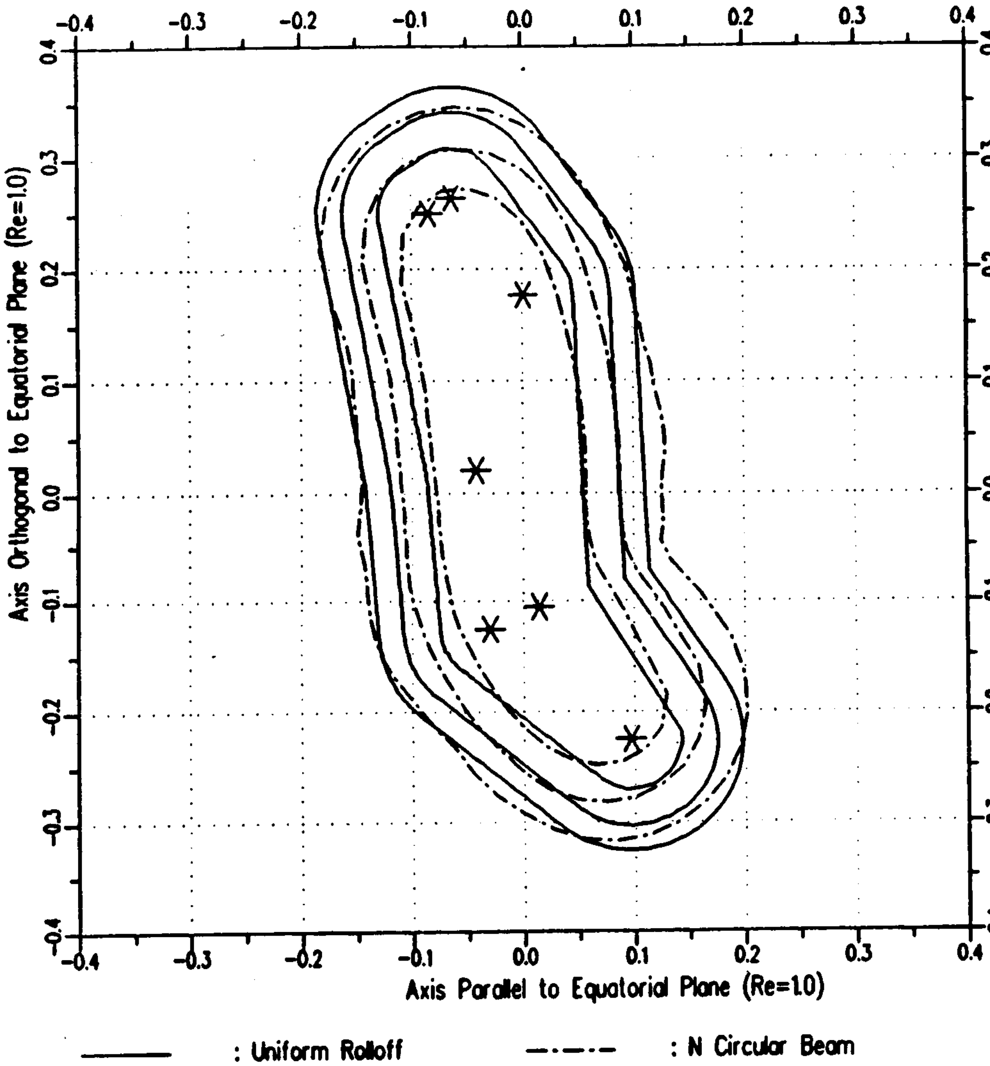

Figure 3.20: Overlay plot of the resulting gain contours for a Chilean satellite at −50° W using the uniform rolloff from a convex polygon and the 8 beam design of Figure 3.14. The beam radius is $0.045R_e$ in both cases.

C -2

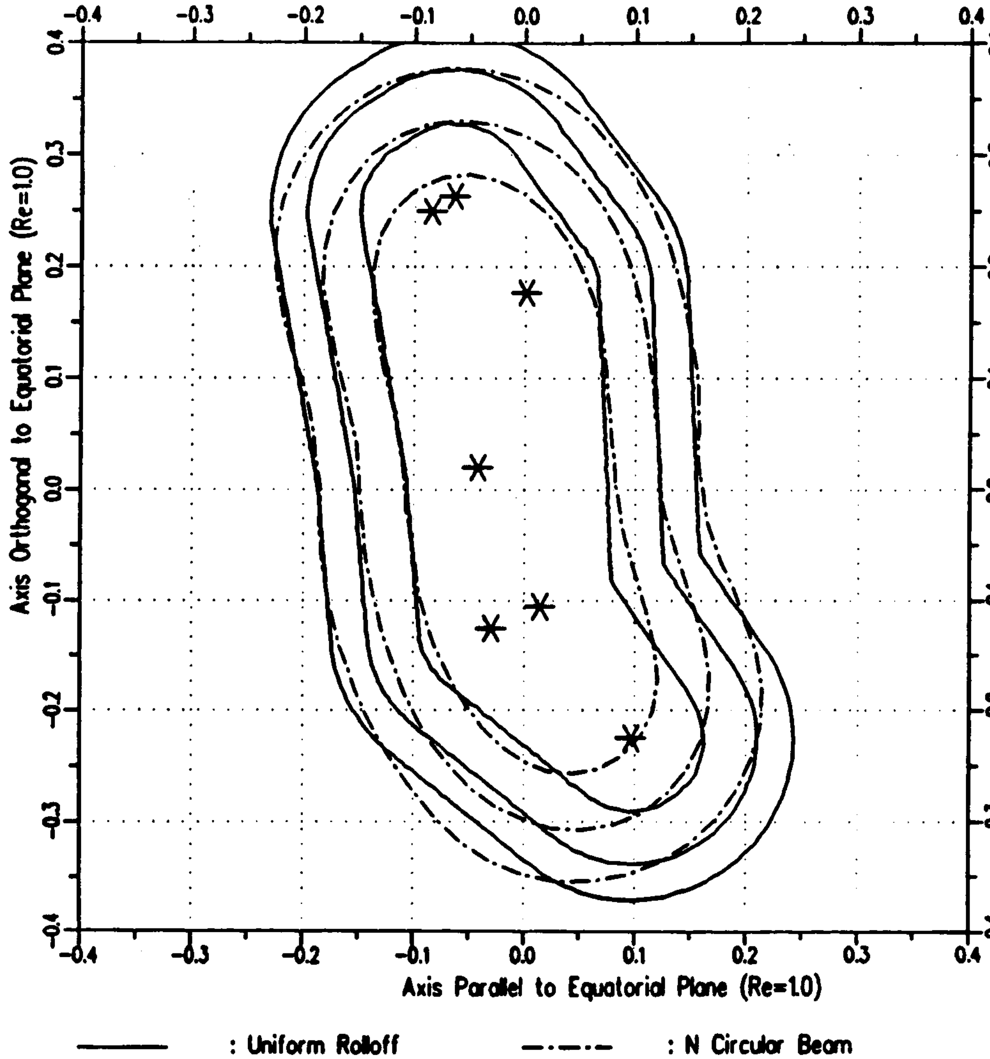

Figure 3.21: Overlay plot of the resulting gain contours for a Chilean satellite at $-50°$ W using the uniform rolloff from a convex polygon and the 5 beam design of Figure 3.12. The beam radius is $0.065R_e$ in both cases.

beamwidth is increased, the contours begin to more and more closely resemble the "fast rolloff" contours. This is especially evident in the bulge which occurs at the sides of the service area.

3.6.3 Brazilian Satellite at $-50°$ W

The second set of plots show the results from using the methods described for a satellite serving Brazil located at $-50°$ W. Figure 3.25 shows the contours obtained with the standard FSS elliptical pattern. Figure 3.26 shows the contours obtained with the "fast rolloff" elliptical half-power pattern.

Three different circular sub-beam designs have been developed for the Brazilian satellite at this location. The first, shown in Figure 3.27, uses 9 sub-beams with radii of $0.13R_e$. The contour plot which results from this design is shown in Figure 3.28. A second design uses 15 sub-beams with radii of $0.10R_e$. This is shown in Figure 3.29. The resulting contour plot is shown in Figure 3.30. A third design is shown in Figure 3.31. This result uses 51 sub-beams with beam radii of $0.045R_e$. The results from using this pattern are shown in Figure 3.32.

The results from these plots again indicate the result that as a smaller sub-beam radius is used, the -3 dB contour of the satellite antenna can be made to more closely follow the border of the service area. For the 51 sub-beam design, the off-axis angle required to get the relative gain down to -18 dB is very large compared to that required in the other beam designs with larger sub-beams. This effect would appear to be caused by the flat portion of the voltage pattern used. As the test point is moved farther and farther from the origin, the distance from most of the sub-beams reaches the point where the voltage recieved from it will be somewhere in this constant region. The value of the summation over all of the sub-beams used

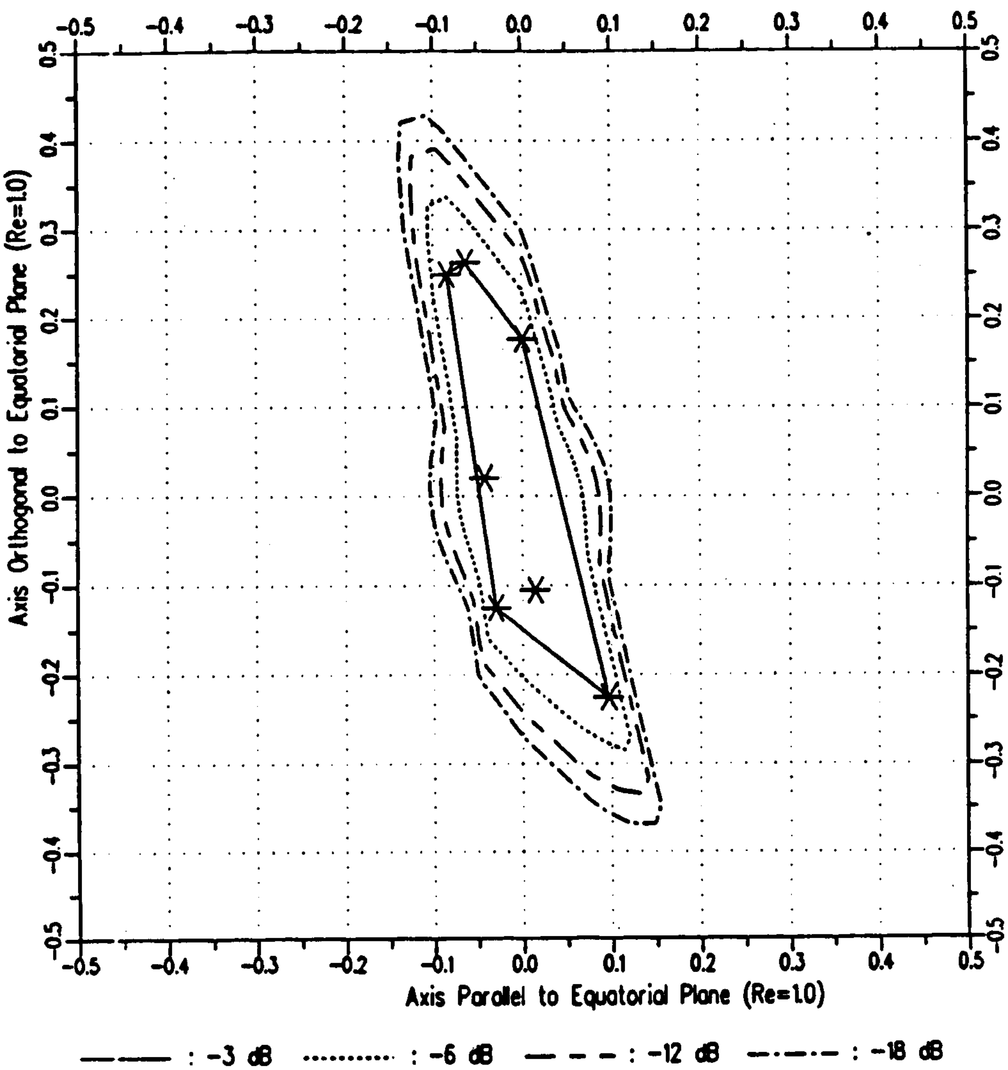

Figure 3.22: Gain contours for a Chilean satellite at $-50°$ W using the projection through center method with a minimum beamwidth of $.05R_e$.

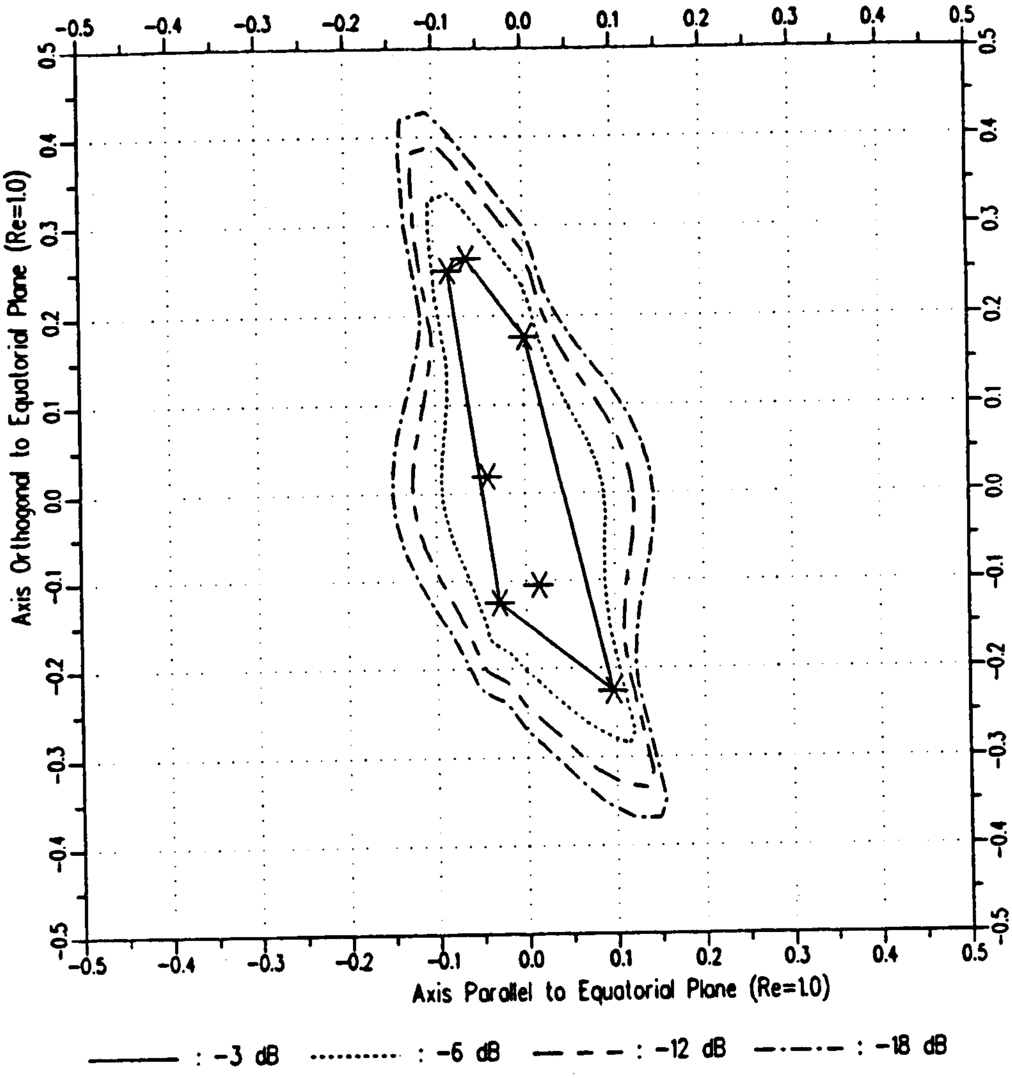

Figure 3.23: Gain contours for a Chilean satellite at $-50°$ W using the projection through center method with a minimum beamwidth of $.09R_e$.

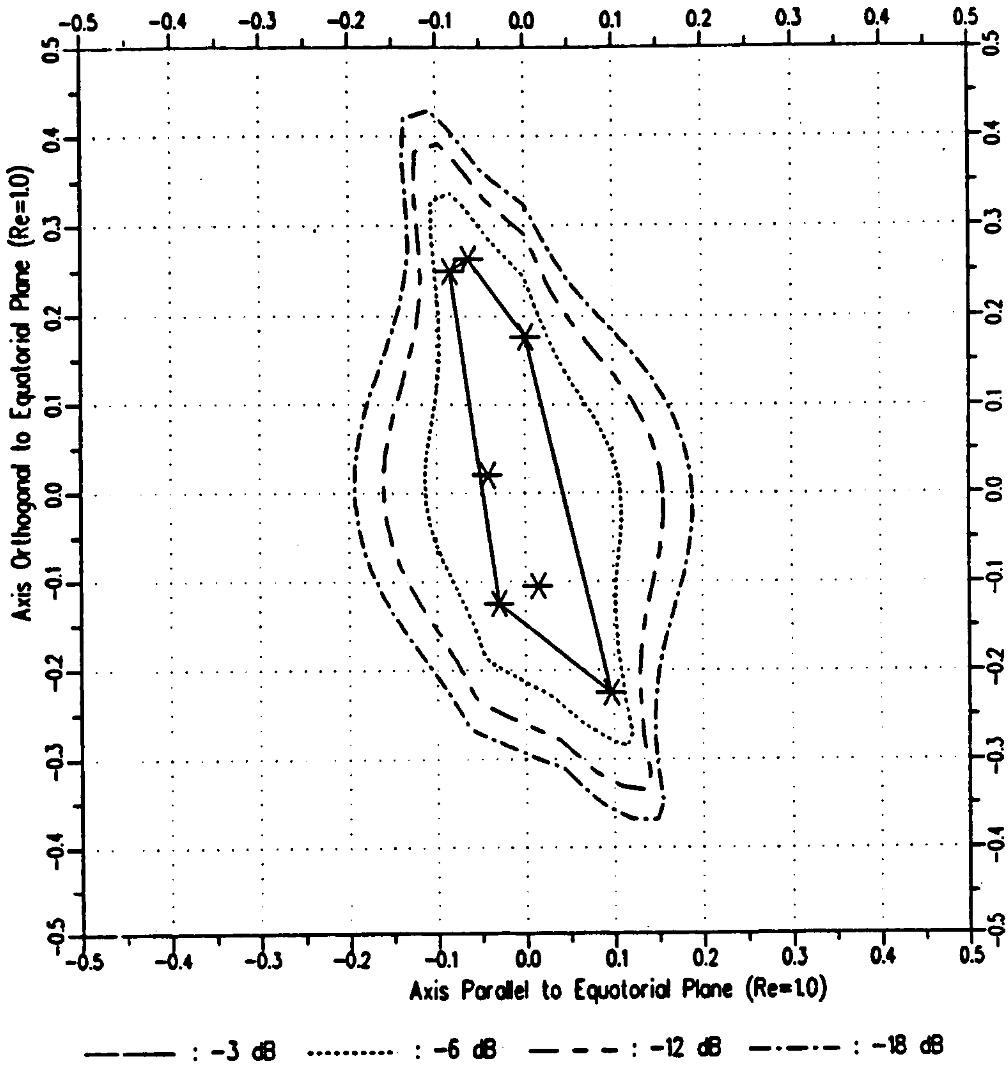

Figure 3.24: Gain contours for a Chilean satellite at $-50°$ W using the projection through center method with a minimum beamwidth of $.13R_e$.

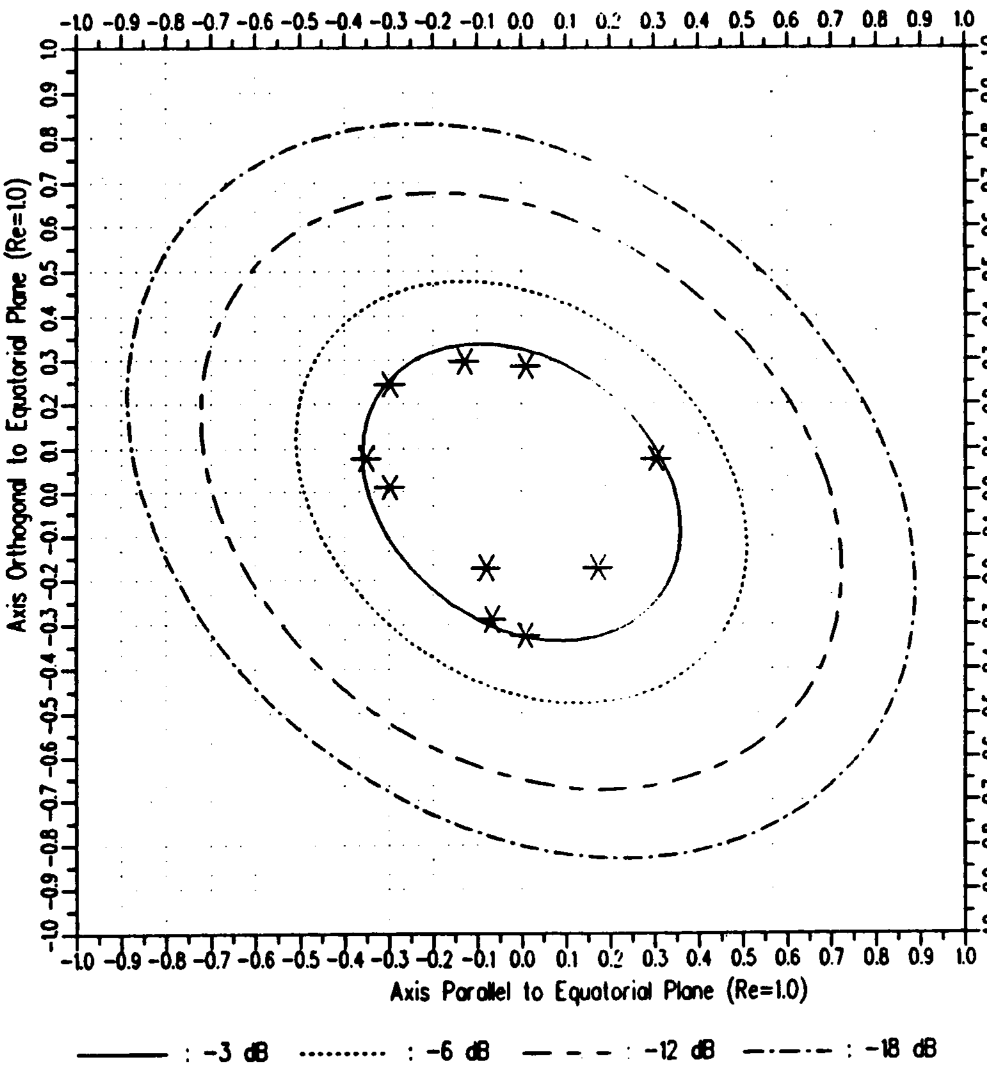

Figure 3.25: Gain contours for a Brazilian satellite at $-50°$ W using the FSS elliptical pattern.

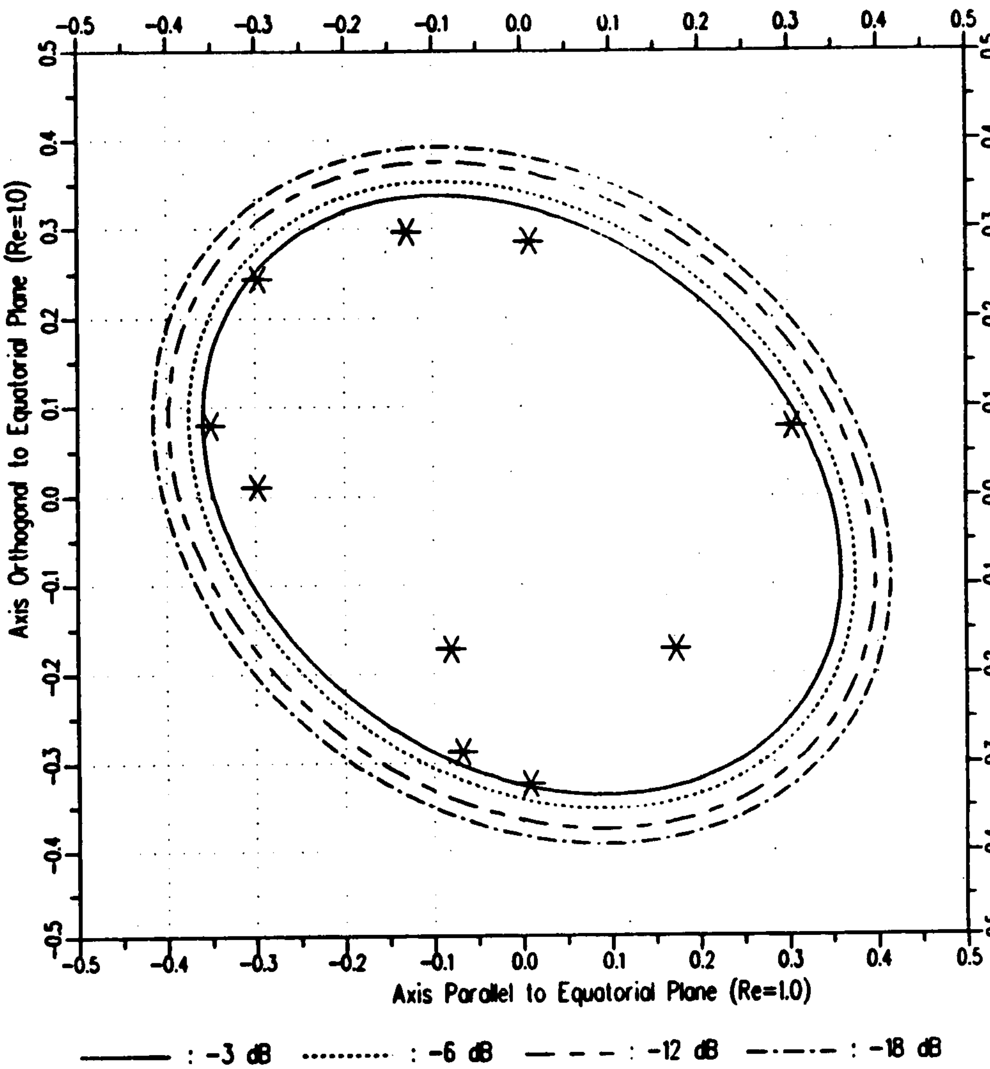

Figure 3.26: Gain contours for a Brazilian satellite at $-50°$ W using the "fast rolloff" elliptical half-power pattern.

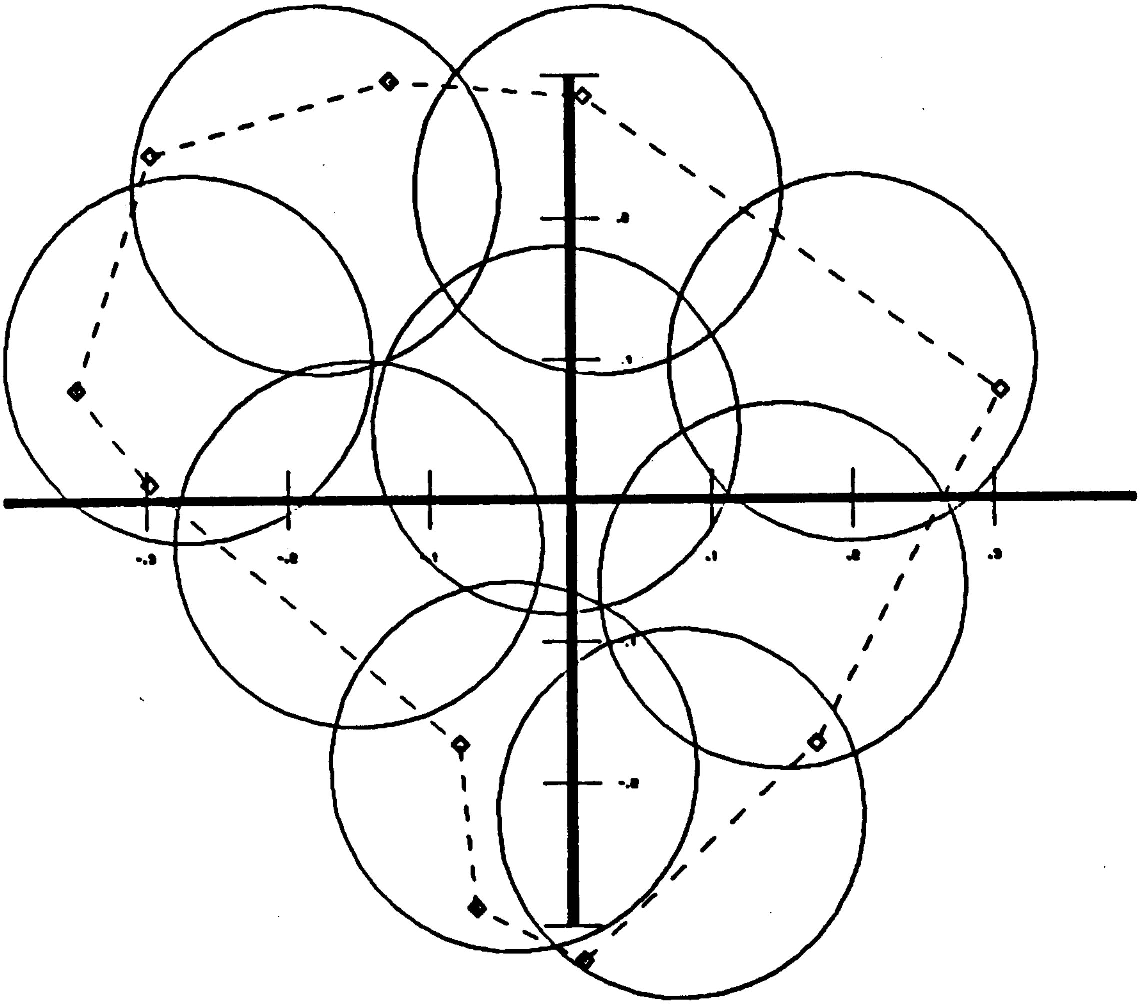

Figure 3.27: Nine-beam design for a Brazilian satellite at $-50°$ W using a beam radius of $.13R_e$.

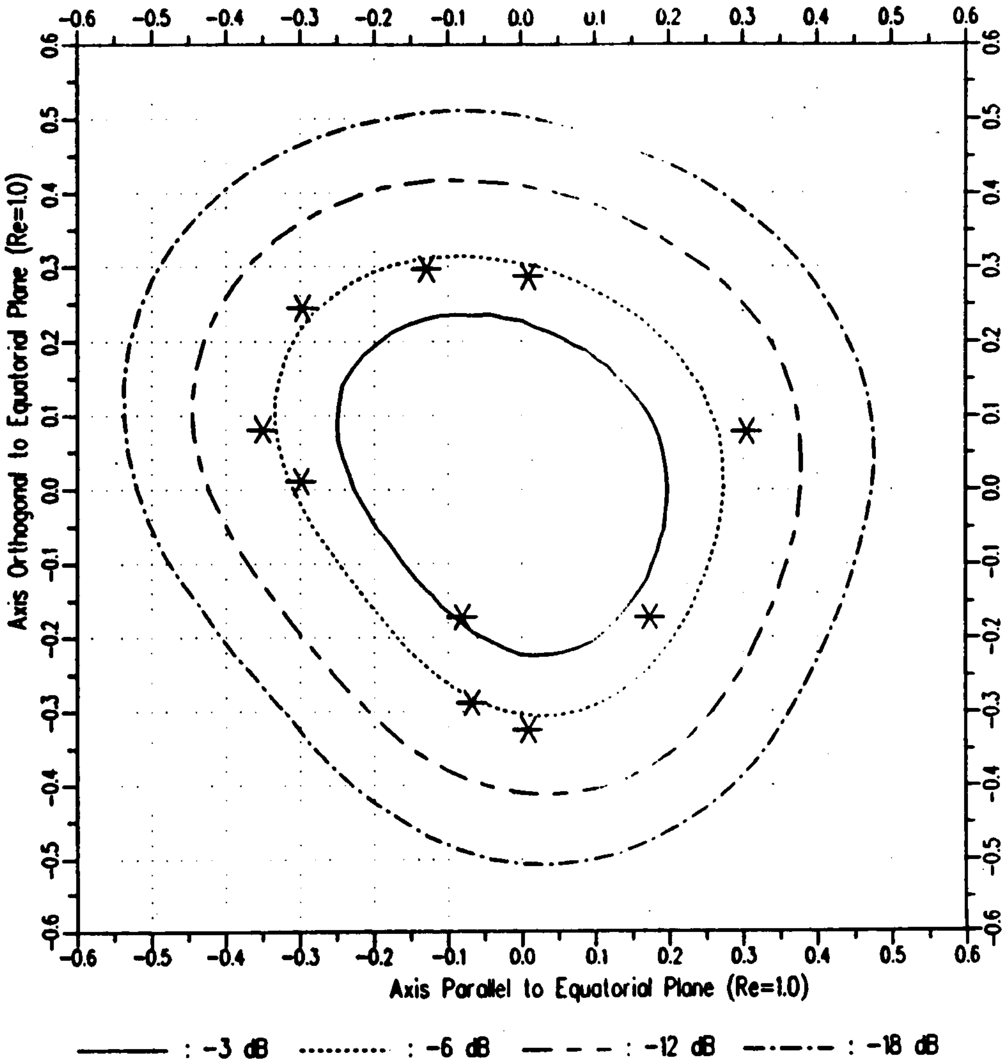

Figure 3.28: Gain contours for a Brazilian satellite at $-50°$ W using the nine-beam design with a $.13R_e$ beam radius.

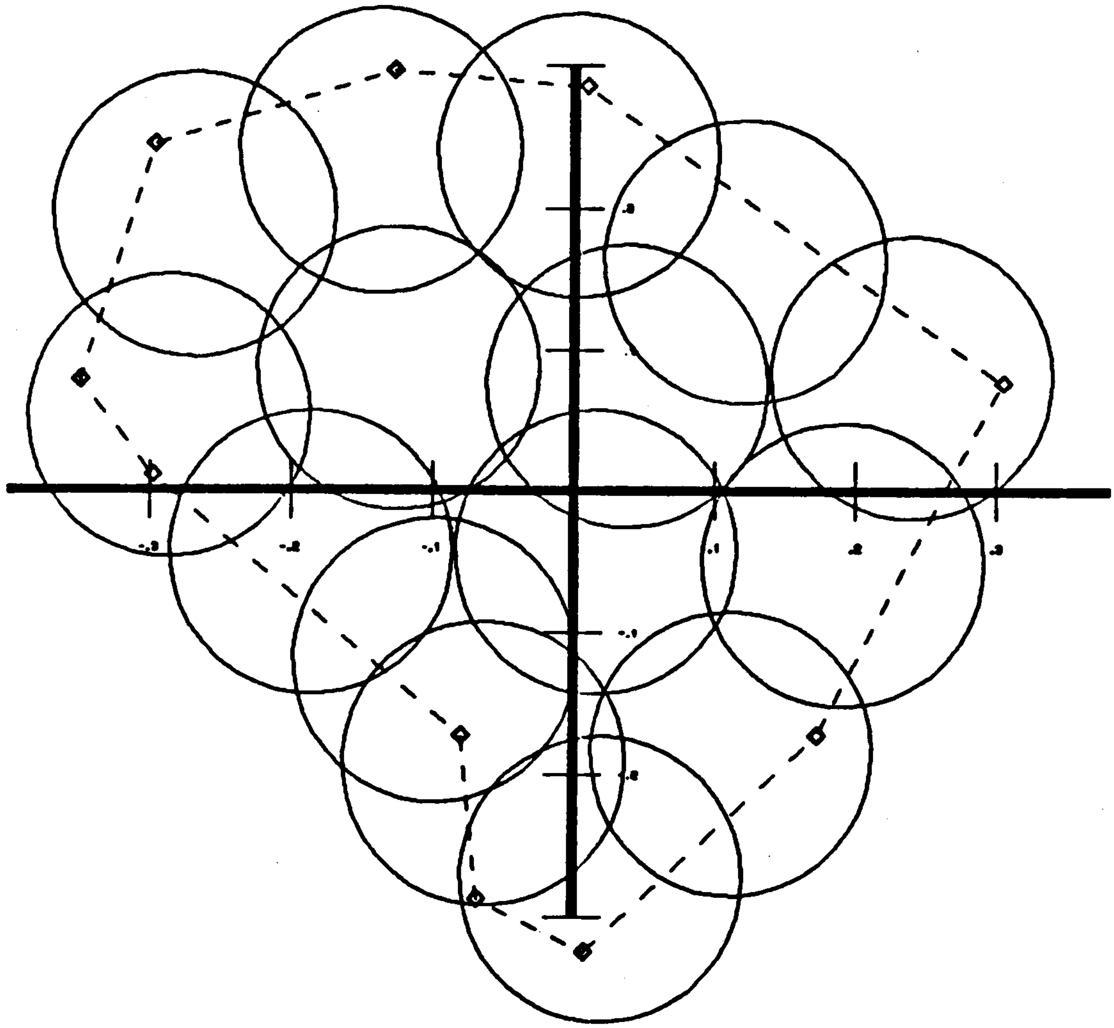

Figure 3.29: Fifteen-beam design for a Brazilian satellite at $-50°$ W using a beam radius of $0.1R_e$.

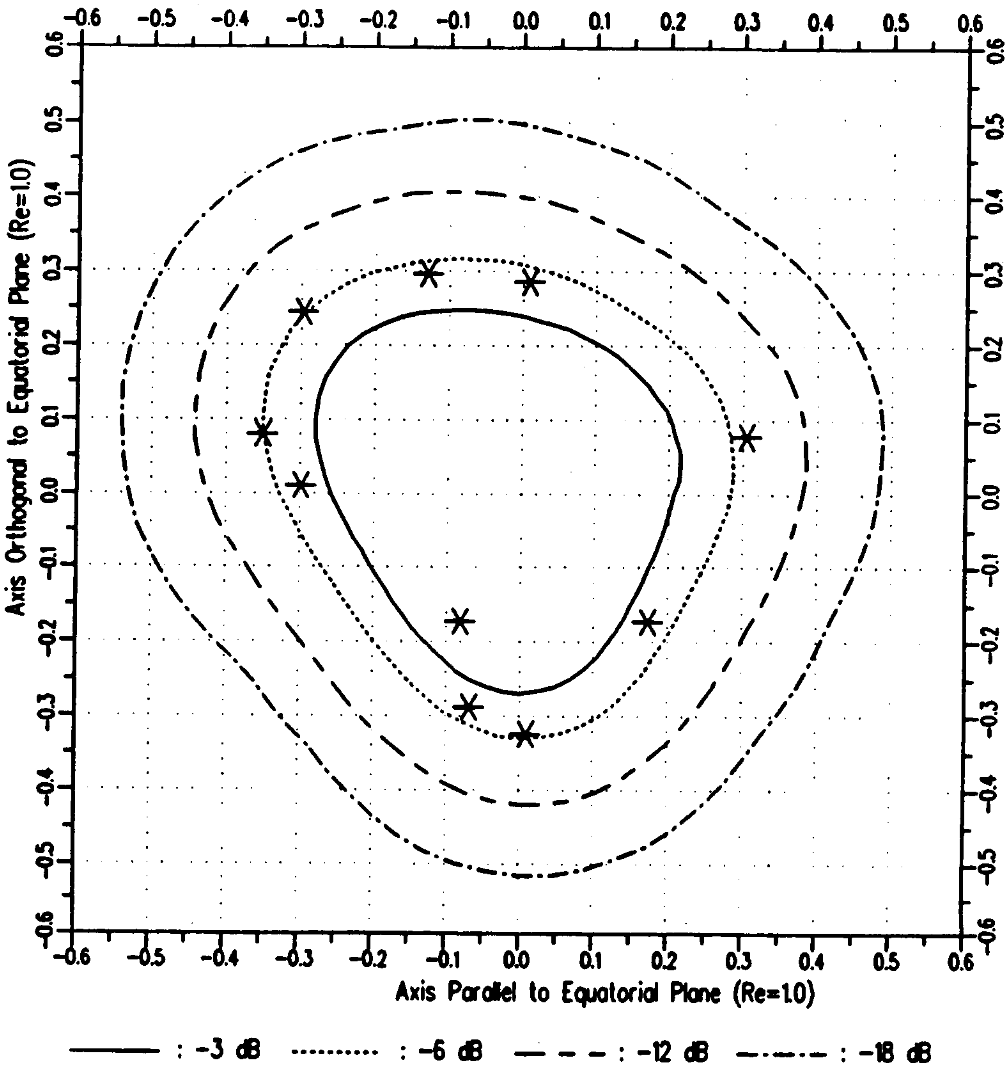

Figure 3.30: Gain contours for a Brazilian satellite at $-50°$ W using the fifteen-beam design with a beam radius of $0.1R_e$.

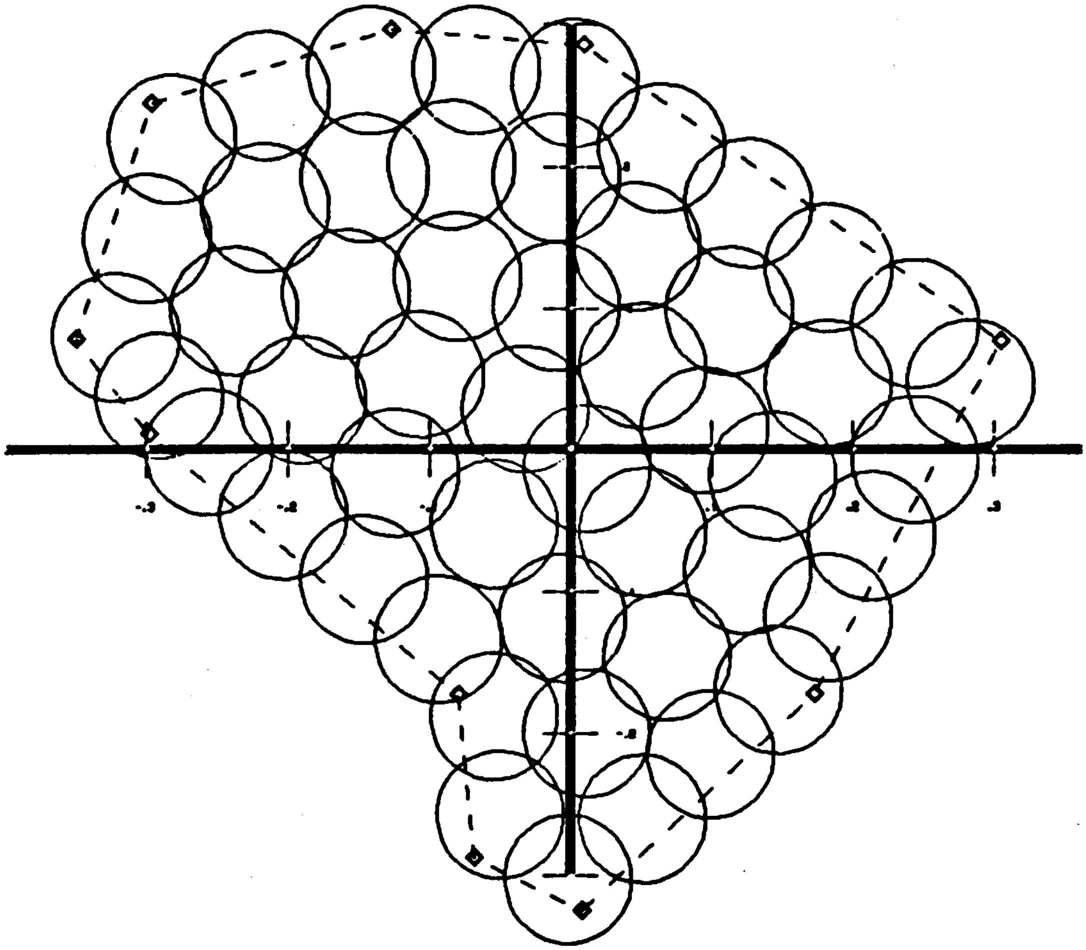

Figure 3.31: 51-beam design for a Brazilian satellite at $-50°$ W using a beam radius of $0.045R_e$.

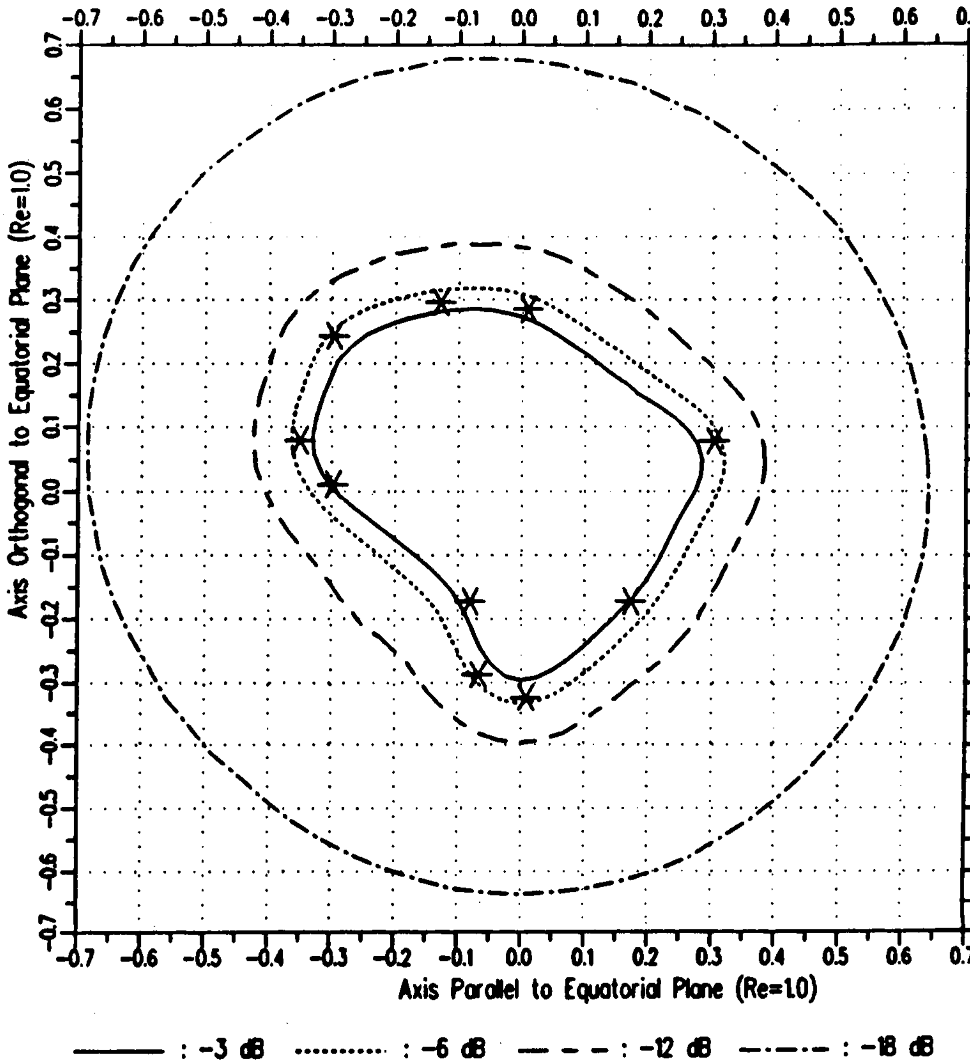

Figure 3.32: Gain contours for a Brazilian satellite at $-50°$ W using the 51-beam design with a beam radius of $0.045R_e$.

to find the relative gain will remain at approximately the same value until the test point is far enough away that the individual signals received from several of the sub-beams are out of the constant portion of the reference pattern and are decaying again. Note that this is due to the assumption that the contributions from all of the sub-beams are adding in phase.

Figures 3.33 and 3.34 show the results obtained with the uniform rolloff patterns. Figure 3.33 shows the contours using a uniform rate of rolloff from a concave service area polygon and an assumed beam radius of $0.13R_e$. Figure 3.34 shows the same thing for an assumed beam radius of $0.1R_e$. Figures 3.35 and 3.36 are overlay plots of the contours obtained using the uniform rolloff method and the n-beam method for these values of the beam radius.

Figures 3.36 and 3.37 show the results from using the method of taking a projection through the center with two different constraints on the minimum beamwidth. For a service area as large as Brazil, the minimum beamwidth constraint has very little effect. It only comes into play when the projection extends across the most narrow region of the service area.

3.6.4 Summary

Gain contour plots have been presented for the various methods for modelling shaped beams that have been attempted. Each of these methods is based on a set of assumptions about how the service area is being covered with sub-beams and the distribution of interference to areas outside the service area.

The elliptical half-power pattern with "fast rolloff" outside the service area polygon is a modification of the standard method adopted for satellite regulation where elliptical patterns were assumed for satellite antennas. Instead of a pattern where

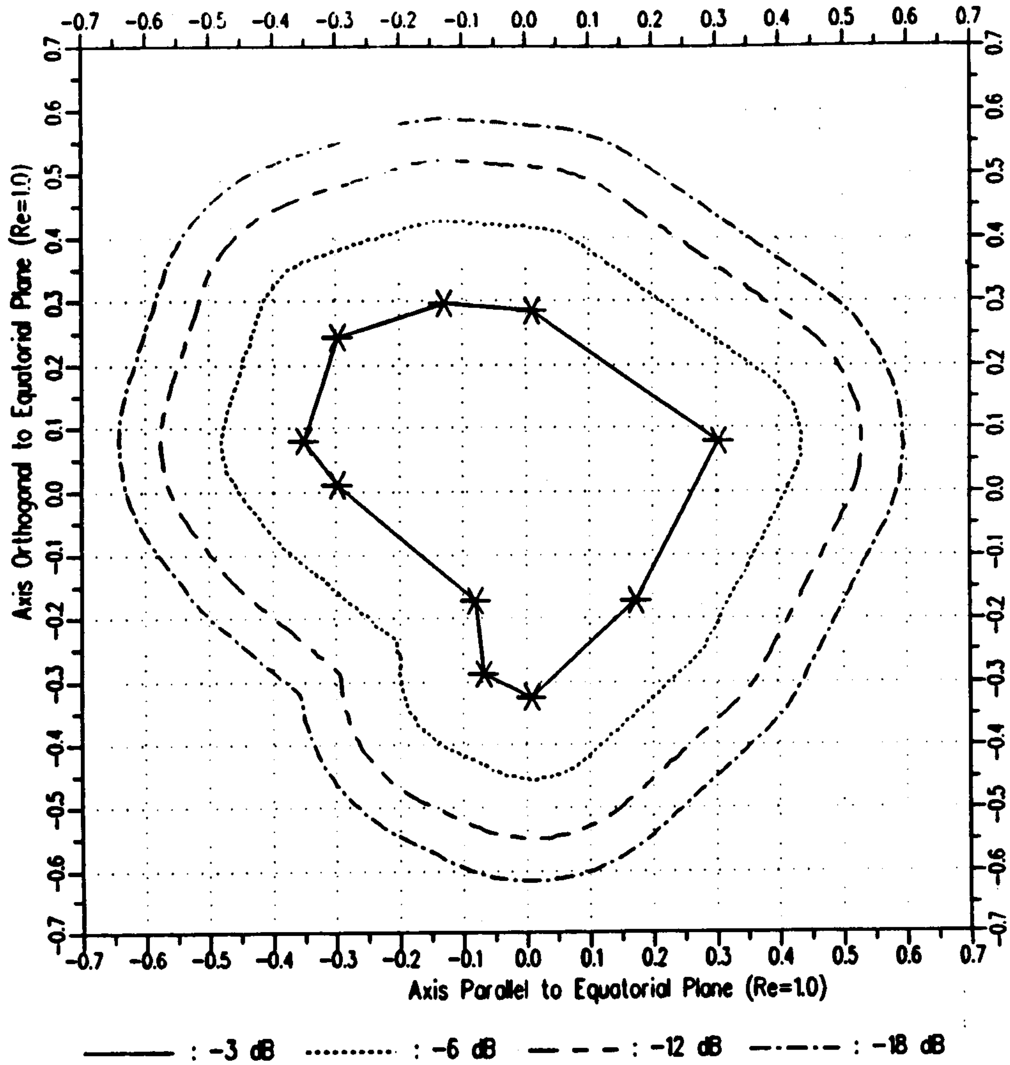

Figure 3.33: Gain contours for a Brazilian satellite at $-50°$ W using the uniform rolloff method from a concave polygon with an assumed beam radius of $0.13R_e$.

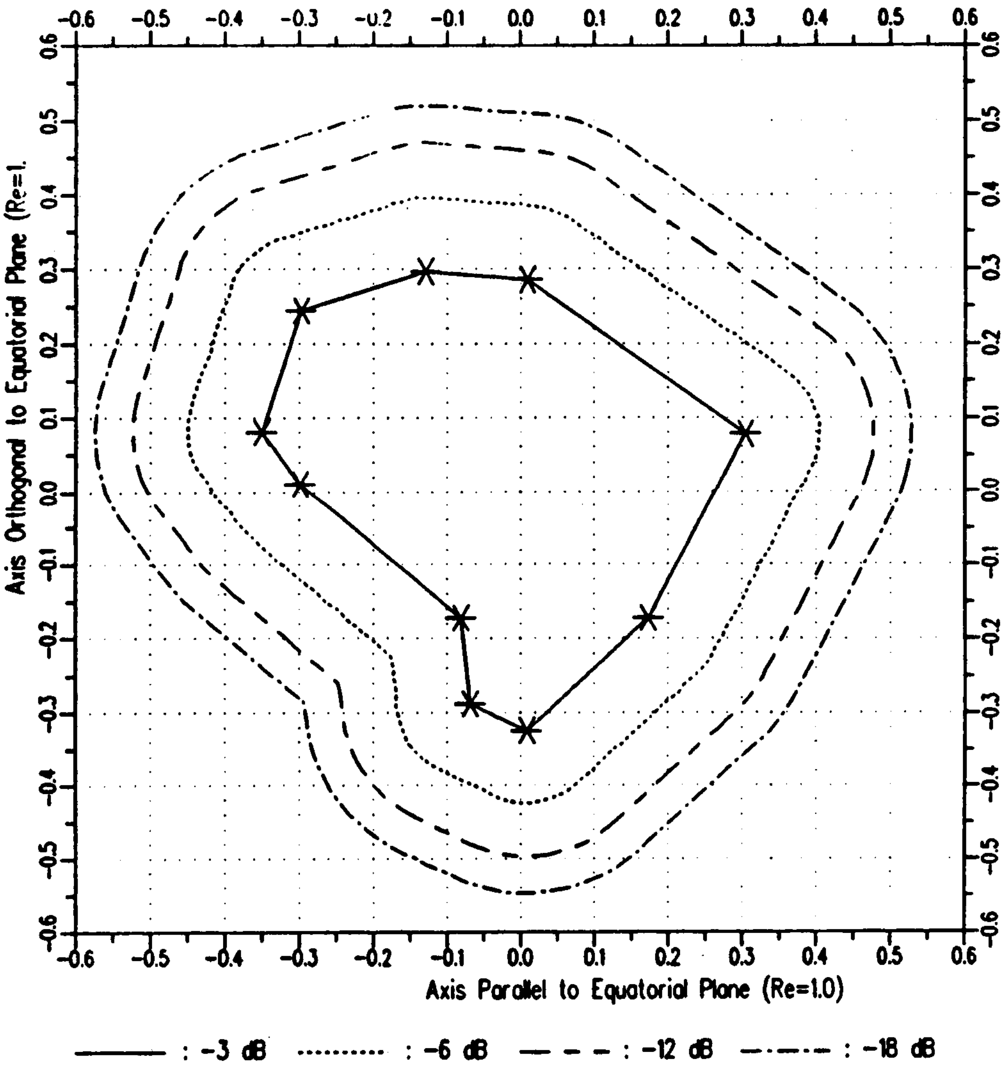

Figure 3.34: Gain contours for a Brazilian satellite at $-50°$ W using the uniform rolloff method from a concave polygon with an assumed beam radius of $0.1R_e$.

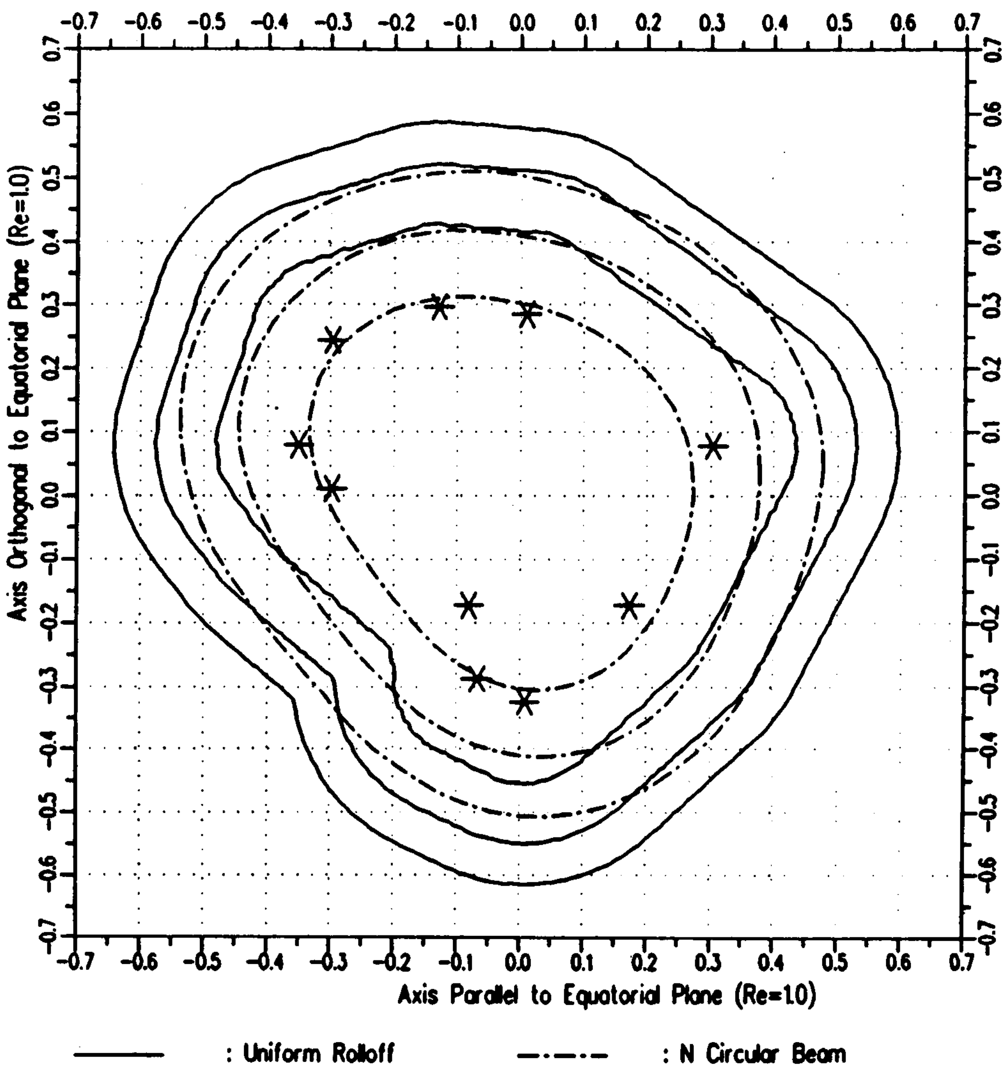

Figure 3.35: Overlay plot of the gain contours for a Brazilian satellite at $-50°$ W using the uniform rolloff method from a concave polygon and a nine-beam design, both of which have an assumed beam radius of $0.13R_e$.

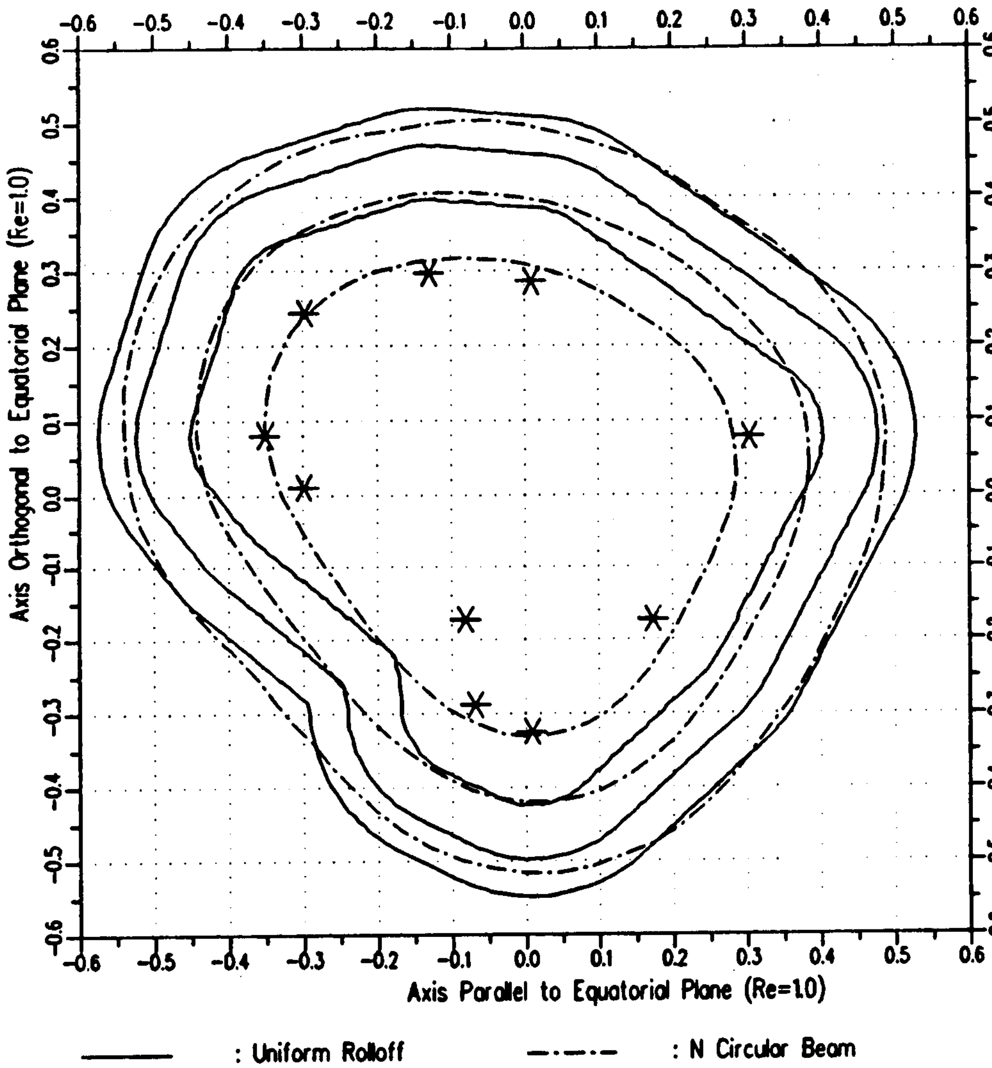

Figure 3.36: Overlay plot of the gain contours for a Brazilian satellite at $-50°$ W using the uniform rolloff method from a concave polygon and a fifteen-beam design, both of which have an assumed beam radius of $0.1R_e$.

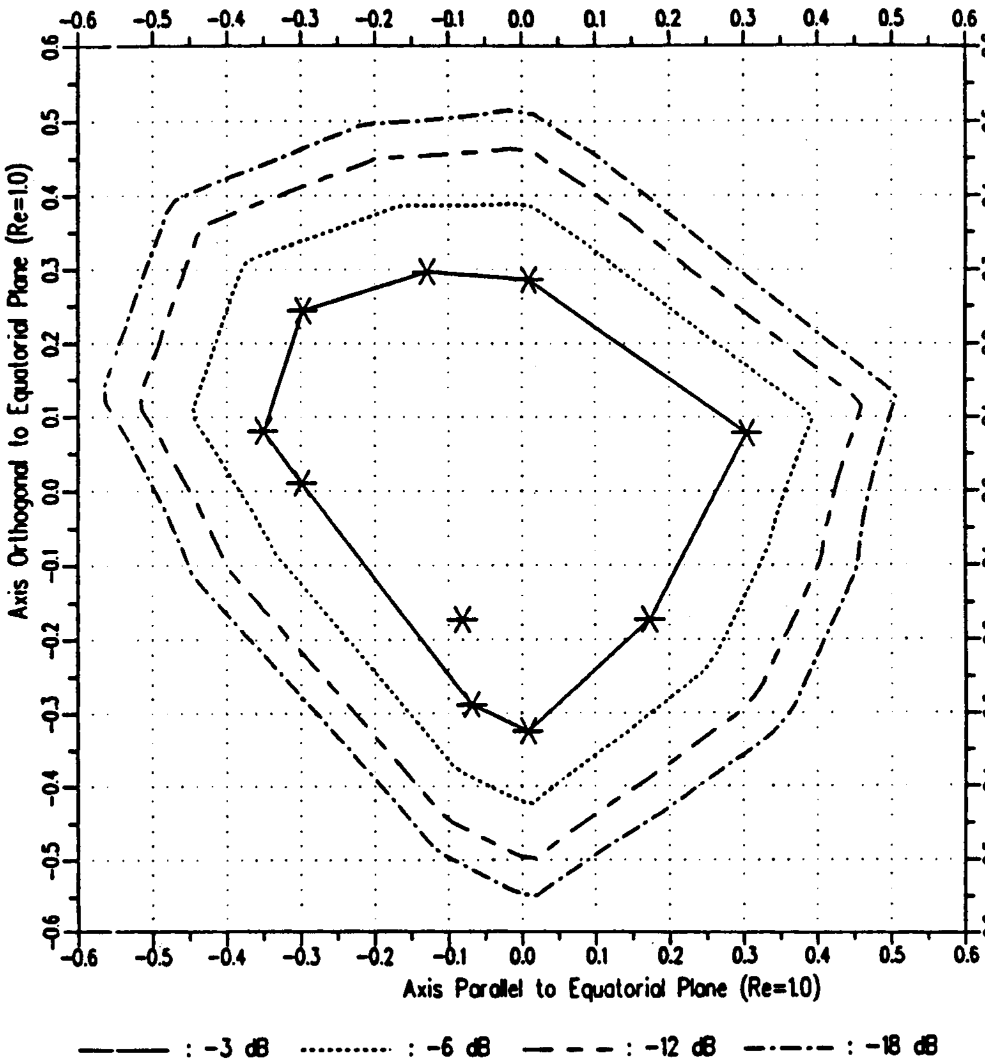

Figure 3.37: Gain contours for a Brazilian satellite at $-50°$ W using the projection through center method with a minimum beamwidth of $.1R_e$.

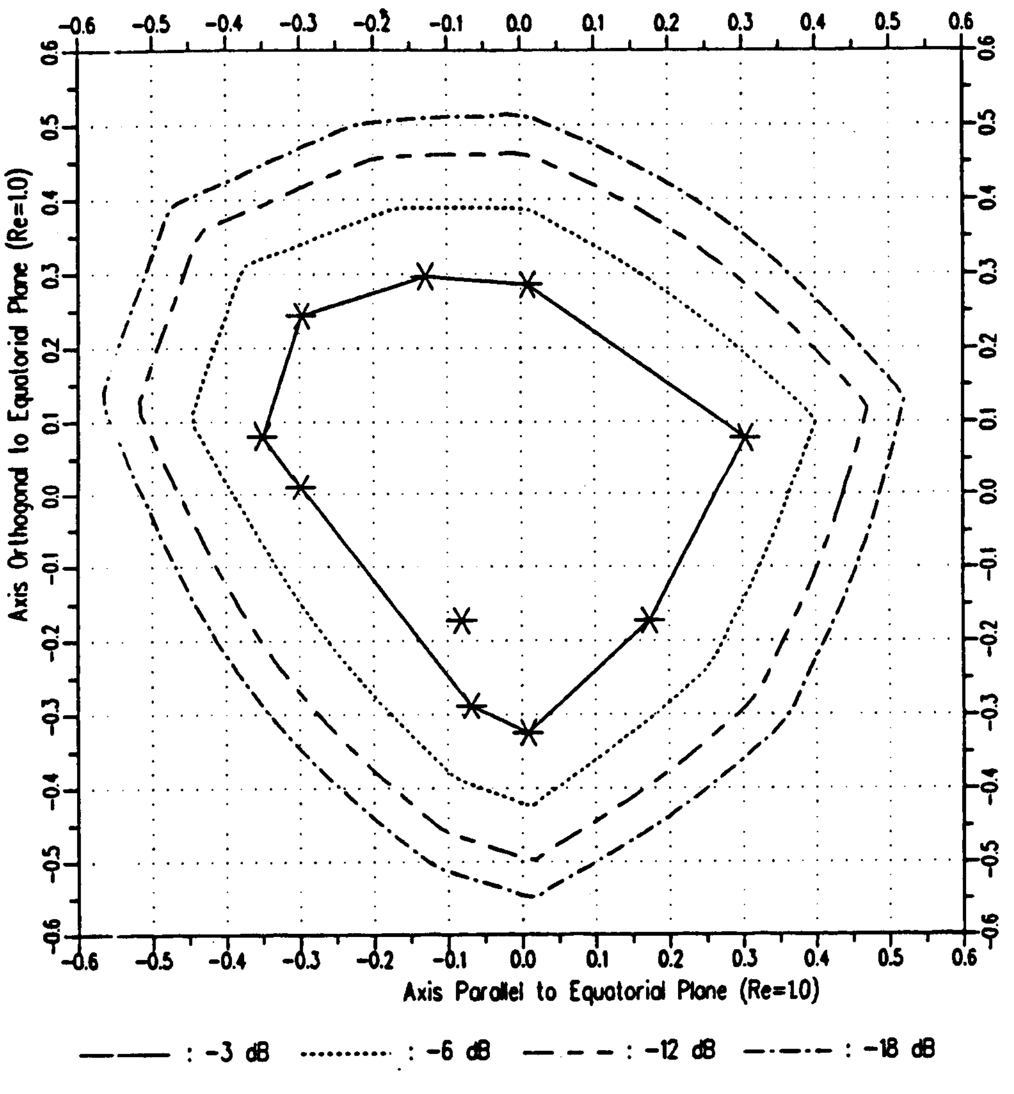

Figure 3.38: Gain contours for a Brazilian satellite at $-50°$ W using the projection through center method with a minimum beamwidth of $.2R_e$.

the relative gain is determined solely from the ratio of the off-axis angle to the measured half-power beamwidth, the relative gain in this pattern is a function of the actual values of both. The method is simple to implement since it involves the same angle calculations as with elliptical patterns and is a completely consistent model once the assumptions about the rate of rolloff are made.

The method which uses a uniform rate of rolloff from the border of the service area polygon is very simple to implement. It assumes that the service area has been covered with uniform circular beams. Under this model, the -3 dB contour is represented by the service area polygon and the relative gain of the shaped-beam antenna falls off from the -3 dB contour as would a single circular beam of the specified radius. In essence, it assumes that a test point outside the service area polygon is only receiving significant interference from one feed of the multiple-feed antenna. The contours obtained with this method are similar to those obtained with the n-beam method except when the number of beams is large. The assumption that the -3 dB contour will exactly follow the outlines of the service area is clearly a very optimistic one unless the size of the sub-beams is very small. If a more conservative model is desired, than the service area polygon can be forced to be convex.

The method of taking a projection through the center of the service area assumes that the service area is being covered with sub-beams (generally not circular) in such a way that the number of beams across the service area is constant. This assumption results in contours which more closely resemble the "fast rolloff" pattern contours than the n circular sub-beam contours. However, for service areas of a uniform shape, such as Brazil, this results in contours which are not too different from those obtained with the uniform rolloff method as the calculated "beamwidth" is

approximately the same in any direction. It also uses the service area polygon as the -3 dB contour and is in that sense too optimistic.

The n-beam method involves several approximations which would require further study to be justified. One is the assumption that the aimpoint of the satellite is always the point of maximum gain regardless of the distribution of the sub-beams. The second is the fact that as presently implemented, all of the sub-beams add in phase. It is this second assumption that leads to a large amount of power spillover into neighboring regions when the number of beams is large. Contours calculated under these assumptions and with the idealized voltage pattern given by 3.42 are somewhat similar to the uniform rolloff contours. The beam designs themselves are quite subjective, and for that reason, this method could not really be used for purposes of regulation but only to indicate the types of contours that a reasonable regulatory pattern should produce.

3.7 The Effects of Shaped Beams on the Required Separation Calculations

This section compares the results obtained when the "fast rolloff", elliptical half-power, pattern is used for both the satellite transmitting antenna and receiving antenna in place of a standard elliptical pattern. This is the only type of shaped-beam pattern that can presently be used with the required separation program "DELTA". The version of the pattern described by Equation (3.2) is used. The earth station patterns used are identical to the ones used in the calculations of Chapter 2 with 4.5 m ground station antennas assumed. The scenario considered is the same one as in Chapter 2, i.e., South America.

Table 3.1 shows the new maximum required separation matrix (ΔS matrix) that is obtained when the shaped beam pattern is used with a link (C/I) requirement of 30 dB. This table is the same as Table 2.4 except that the satellite antenna patterns have been changed. Table 3.2 shows the percentage reduction in the separation requirements when the shaped beam pattern is used as compared to the standard elliptical pattern. The numbers preceeded by a "+" indicate places where there is an increase in the minimum required separation when the shaped beam pattern is used.

Some general rules can be stated as to the effects of the shaped beam pattern. For adjacent countries, the shaped beam pattern has no effect at all. This is because the required separation calculations are performed for the worst test points in each administration. For a pair of administration's whose service areas share a common border, the worst test points will be those right along the border. These points will always lie along or just inside the -3 dB contour of the interfering satellites transmitting or receiving antenna and will thus receive significant interference. Shaped beams cannot compensate for this effect. This implies that the largest required separation values, which occur for administrations with adjacent service areas, will not be improved by using the shaped beam pattern. Required separation values for countries which do not have a common border are substantially reduced by using the shaped beam pattern. These values are the relatively small ones in the matrix.

The ΔS matrix does not fully describe the effects of the shaped beam pattern, however, since it only presents the maximum required separation over the entire arc. For some cases, the effects of the pattern differ depending on the mean orbital location of the two satellites. Figures 3.39 and 3.41 show comparitive plots of

Table 3.1: Required Separation Matrix Using Shaped Beams For South America, $(C/I)_L = 30$ dB.

	Brazil	Guyana	Paraguay	Uruguay	Argentina	Venezuela	Bolivia	Chile	Columbia	Peru	Ecuador
Surinam Fre. Guiana	4.88	5.09	0.00	0.00	0.46	4.19	0.48	0.44	1.32	0.48	0.23
Brazil		5.39	5.22	4.84	5.39	4.93	5.09	4.13	5.44	5.60	3.14
Guyana			0.00	0.00	0.49	5.28	0.59	0.47	2.31	0.57	0.39
Paraguay				2.66	4.97	0.27	4.83	3.81	0.54	1.70	0.00
Uruguay					4.71	0.00	0.83	3.62	0.35	0.48	0.00
Argentina						0.56	4.84	5.24	0.62	1.44	0.47
Venezuela							0.62	0.57	5.56	1.34	1.28
Bolivia								5.03	0.70	5.19	0.59
Chile									0.62	4.95	0.51
Columbia										5.05	4.78
Peru											5.07

Maximum Required Separation in Degrees Over Arc

Table 3.2: Percentage Reduction in Maximum Required Separation Values From Using Shaped Beams for the Administrations of South America. $(C/I)_L = 30$ dB. ("+" indicates that the maximum required separation increases)

	Brazil	Guyana	Paraguay	Uruguay	Argentina	Venezuela	Bolivia	Chile	Columbia	Peru	Ecuador
Surinam	0.00	0.00	100.	100.	62.0	+.48	58.9	76.3	44.1	66.4	79.5
Fre. Guiana											
Brazil		0.00	0.00	0.00	0.00	0.00	0.00	2.13	0.00	0.00	9.25
Guyana			100.	100.	59.2	0.00	53.5	73.1	20.6	68.2	65.5
Paraguay				18.9	0.00	76.7	0.00	1.29	58.8	42.4	100.
Uruguay					0.63	100.	62.1	+.55	67.9	70.2	100.
Argentina						53.3	0.00	0.00	57.8	59.3	65.9
Venezuela							52.3	69.2	0.00	56.8	47.1
Bolivia								0.00	75.9	0.00	63.4
Chile									71.8	0.00	78.8
Columbia										0.00	0.00
Peru											0.00

required separation over the common feasible arc for pairs of administrations when the "fast rolloff" patterns are used and when they are not used.

Figure 3.39 shows the importance for an administration such as Chile which has a service area with an irregular shape of an orbital location near the center of its feasible arc. When the shaped beam pattern is used, the required separation between Paraguay and Chile is substantially decreased in the center of the arc. At the ends of the arc it actually is slightly higher when shaped beams are used. This is due to the bulge in the gain contours for Chile at the sides of the service area as seen in Figure 3.40. This figure shows the elliptical half-power pattern contours for the Chilean satellite at $-126°$ W . Thus, the maximum required separation value will be greater even though a substantial improvement in required separation could be achieved in the center of the arc.

Figure 3.41 shows the improvement which can be achieved when shaped beams are used by both Guyana and Columbia. Here again the largest benefit is achieved if the two satellites are located in the center of the arc.

The results presented in this section made use of just one of the methods discussed for modelling the effects of shaped-beam antennas. They should, however, be qualitatively typical of those that would be obtained if the other methods were used, since all of them reduce interference to non-adjacent administrations.

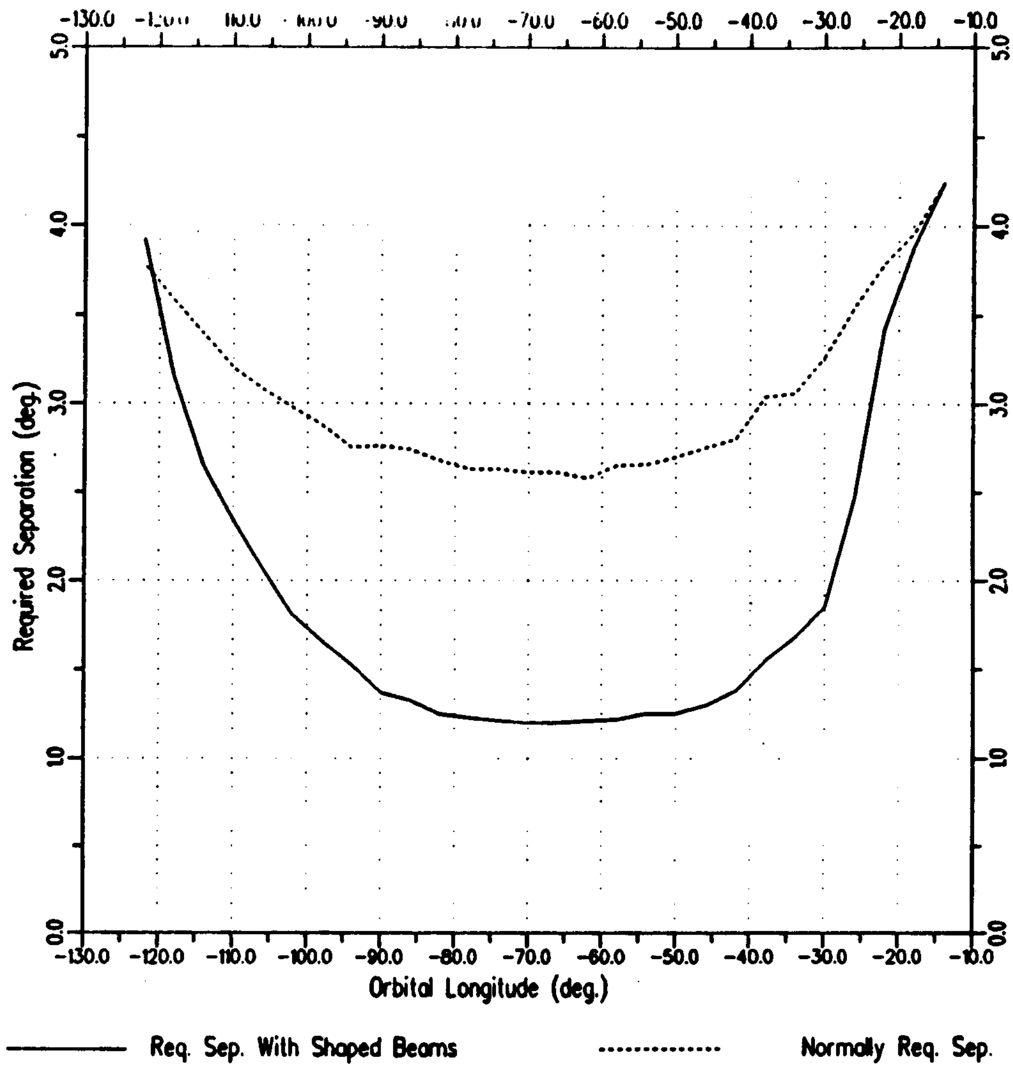

Figure 3.39: Comparison of required separation values for Paraguay and Chile over the common feasible arc when a shaped-beam pattern is used and when an elliptical pattern is used.

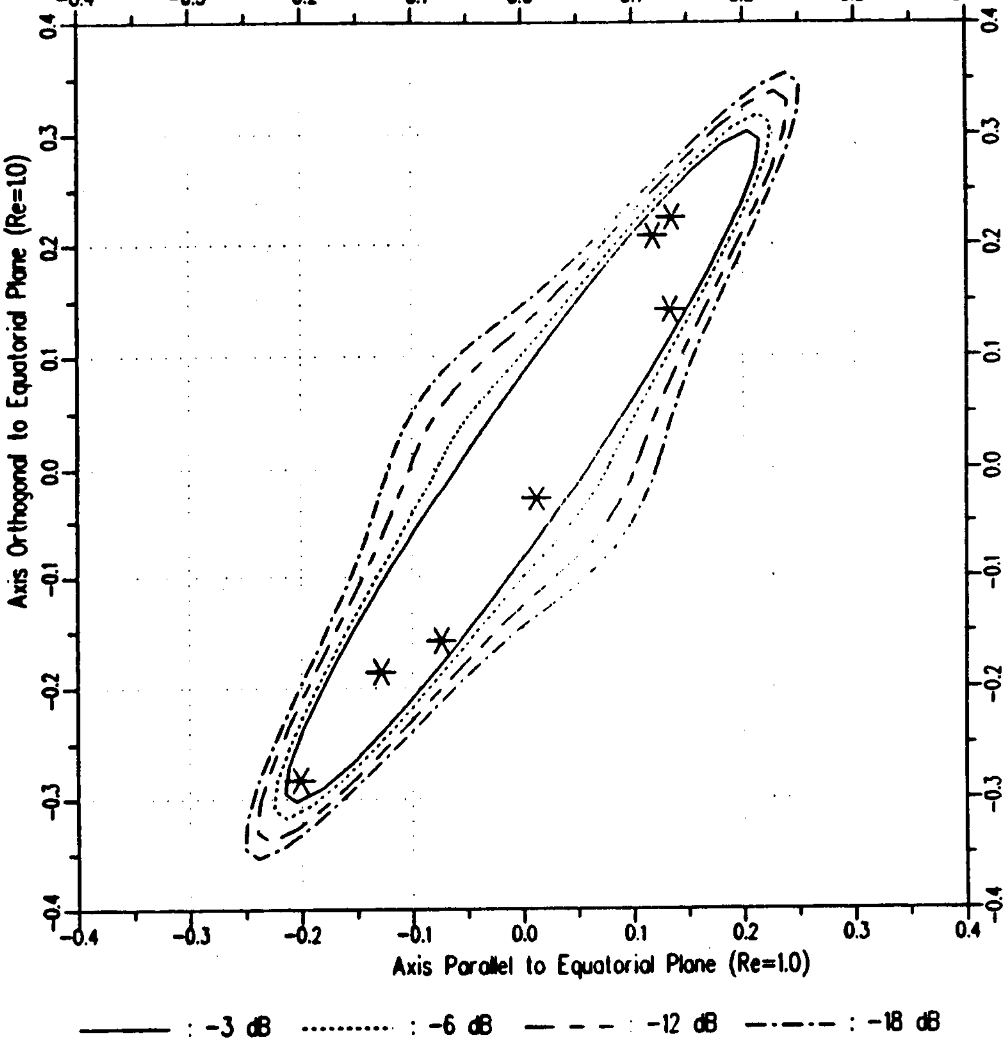

Figure 3.40: Gain contours for a Chilean satellite at −124° W using the "fast rolloff" pattern.

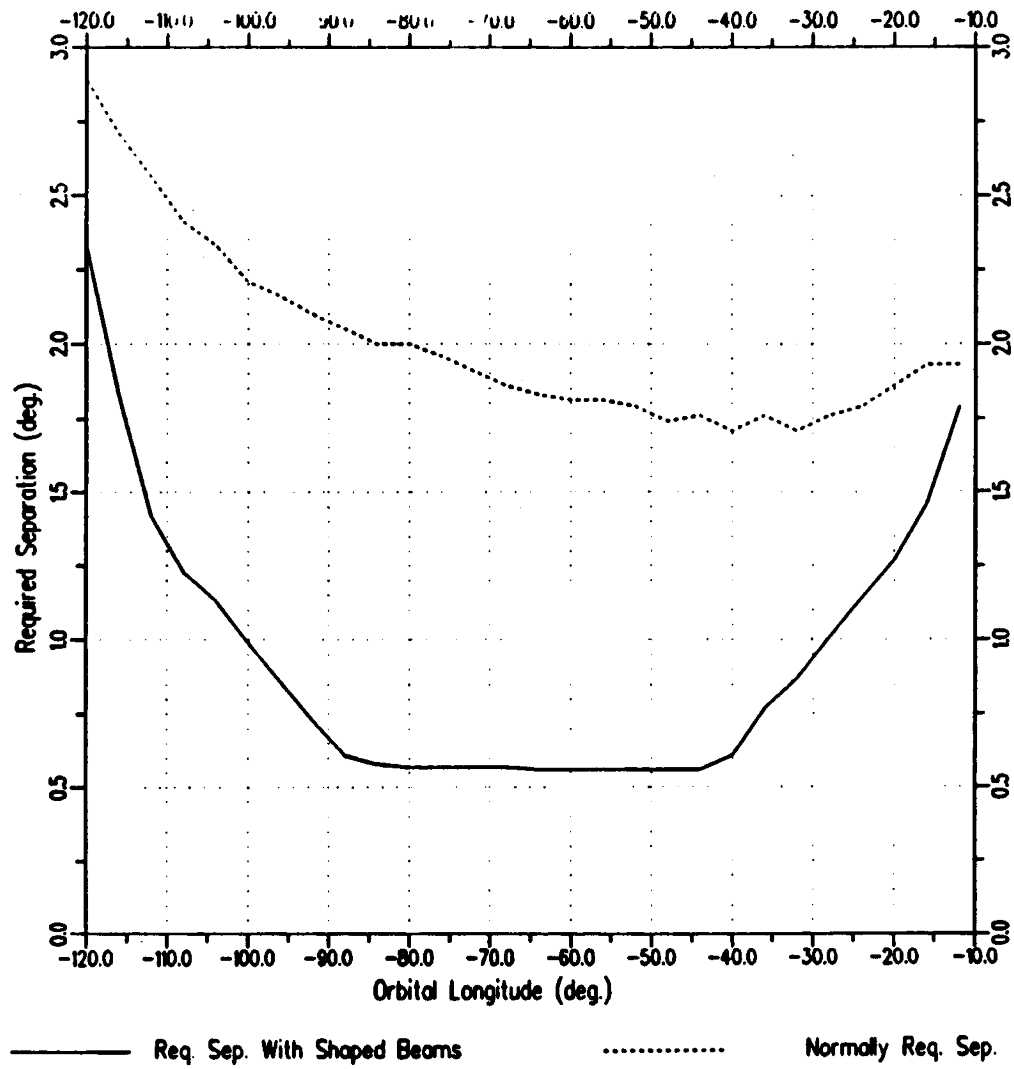

Figure 3.41: Comparison of required separation values for Guyana and Columbia over the common feasible arc when a shaped-beam pattern is used and when an elliptical pattern is used.

Chapter 4

The Aggregate C/I Problem

4.1 Introduction

In the "Delta-S" approach to the orbital assignment problem, constraints on the orbital locations of satellites are determined on a single-entry basis. The minimum required spacing between two satellites to achieve a desired carrier to C/I ratio is determined for all pairs of satellites. While the constraints are determined on the basis of single-entry interference, the actual measure of how good a solution to the orbit allotment problem has been found is determined by the aggregate interference levels present in the satellite links of the administrations in question. Thus to specify single-entry interference requirements that will lead to solutions with acceptable aggregate interference levels, an estimate must be made of the extent to which the worst aggregate C/I ratio can fall below the worst single-entry value.

In the past, when only down-link interference was considered, it was found that the aggregate C/I ratio for a given solution would, in general, not be more than 5 dB below the worst single entry C/I ratio between any pair of satellites [5, pp. 106-108]. This 5 dB margin was originally suggested at the WARC-77 conference [23,

pp. 104-108]. Thus, if the minimum required aggregate C/I ratio was 25 dB, the constraints were calculated on the basis of a single-entry requirement of 30 dB. This practice has been continued in the calculations being done presently. It is not obvious, however, that the margin of 5 dB between the single-entry requirement and the resulting aggregate C/I values will remain sufficient when the interference calculations include the effects of both up-link and down-link interference.

The subject of this chapter is the aggregate interference problem when both up-link and down-link interference are included. The topics covered are the computer program, "MISOUP", to calculate aggregate C/I values, actual cases in which the 5 dB margin between single-entry and aggregate C/I values is exceeded, and a discussion of what should be done if the margin is exceeded.

4.2 New Streamlined SOUP Program

A streamlined version of the orbital analysis program SOUP [14] was developed by Wang to help analyze the aggregate interference problem [5, p. 17 and appendix A]. This program calculated aggregate C/I ratios at all test points of an administration's service area, considering the interference that entered on the down link only. This program has been modified to include interference from both the up and down links in the aggregate C/I calculations. The program considers the worst-case interference that will enter the satellite network of each administration in the orbital assignment solution being tested from all sources of significant interference. Note that when the word "administration" is used in this context it refers to a single satellite network with one satellite serving a single service area. If there are several satellites which all have the same service area they are all considered separate ad-

ministrations. That is, if there are 25 satellites in a scenario that are all serving the U.S., each is considered to be part of a different administration.

The FORTRAN code for the new aggregate C/I computer program is listed in Appendix C. This program will henceforth be referred to as the "MISOUP" program. The inputs to the program are essentially the same as for the required separation program. The test points defining the service areas of each administration must be entered as well as the orbital location of the satellite serving that administration. Since all satellite antennas are assumed to have either elliptical patterns or elliptical half-power patterns, the data for the minimum elliptical beam used at that orbital location must be entered. The data on the types of reference patterns being used for the satellite and earth station antennas must also be entered.

The program output is a listing of the worst total link aggregate C/I value for each administration. The output also lists the worst aggregate C/I ratio on the up link only, the worst aggregate C/I ratio on the down link, and the worst single-entry C/I ratios which occur for both the up link and the down link for each administration.

The first step of the calculation for each administration considered is to calculate the aggregate C/I ratio on the up link. For each interfering administration, the amount of up-link interference presented to the desired up-link signal by a transmitter located at each test point of the interfering administration's service area is calculated. This calculation proceeds as explained in Chapter 1. The largest value of interference power is then taken from among these. The values of the worst-case up-link interference from each administration are summed as noise powers and compared to the desired received power at the desired satellite to determine the worst aggregate up-link C/I ratio.

The down-link calculations then proceed just as they did in Wang's original program, i.e., the down-link C/I ratio is calculated at each test point in the administration considered, including down-link interference from all significant interfering satellites. The worst aggregate down-link C/I value from all the test points in the administration's service area is then chosen.

The worst aggregate down-link C/I value, $(C/I)_{down}$, is combined with the worst aggregate up-link value, $(C/I)_{up}$, using the expression

$$(C/I)_{link}^{-1} = (C/I)_{up}^{-1} + (C/I)_{down}^{-1} \tag{4.1}$$

to yield the worst-case aggregate link C/I value.

4.3 Examples of Aggregate C/I Calculations

This section contains six examples of aggregate C/I calculations for various scenarios that have been examined. These examples demonstrate that the 5 dB margin between the single-entry C/I values and the aggregate C/I values is a reasonable first estimate but that it will not be sufficient in all cases. The first three examples were developed intuitively using calculated $\Delta\phi$ values and a trial-and-error process for assigning orbital assignments to a small group of satellites. Later examples in this chapter come from actual orbital assignments generated with the K-permutation algorithm [6] at OSU. These examples suggest more serious problems that might appear in satisfying the C/I target in the future using a 5 dB margin as new ways are developed to add more satellites within a given orbital arc. As the orbital capacity of the arc is maximized, with more and more satellites being located closer together, the trend will naturally be for aggregate C/I ratios to decrease. Thus,

these examples do not represent the highest level of aggregate interference which could appear when all of the single-entry separation requirements are met.

4.3.1 Example 1

The first example illustrates how the presence of interference on both the up-link and down-link from a number of sources can degrade the aggregate C/I level below the 5 dB margin from the single-entry requirement used in the required separation calculations. It involves a Chilean satellite network receiving interference from a number of satellite networks in nearby administrations.

This example, comes from a list of $\Delta\phi$ values calculated for the following administrations: Argentina, Venezuela, Surinam/French Guiana, Ecuador, Paraguay, Bolivia, Uruguay, and Chile. The single-entry C/I requirement is 32 dB. The "rolloff" pattern described in Chapter 3 (Equation (3.2)) is used for the satellite transmitting antenna of all administrations as well as for the receiving pattern of all satellite antennas. The standard earth antenna pattern described in Chapter 2 is used and a 4.5 m dish diameter is assumed for both the transmitting and receiving antennas on the ground. The Chilean satellite has been fixed at the orbital location of $-50°$ W . The satellites of the other administrations have been spread about this location, with care taken to make sure that all required separation requirements have been met. The distribution of satellites considered is listed in Table 4.1.

An aggregate C/I analysis, made with the MISOUP program described in section 2, indicates that the worst-case link aggregate C/I ratio for Chile is 26.24 dB, over 5.7 dB below the single-entry requirement. The worst aggregate C/I ratio on the down link for the Chilean system is 29.28 dB. This occurs at the test point with latitude -23.0 degrees and longitude -66.5 degrees. The worst single-entry value

Table 4.1: Satellite locations for aggregate C/I calculations of example 1.

Administration	Satellite Location (Longitude)
Bolivia	-44.49
Uruguay	-48.72
Ecuador	-49.36
Surinam/French Guiana	-49.80
Chile	-50.00
Paraguay	-51.42
Argentina	-57.20

on the down link comes from the satellite serving Paraguay and is 32.63 dB. The single-entry down-link C/I ratios from all interfering satellites at the worst test point are listed in Table 4.2.

The worst aggregate C/I ratio on the up link is 29.22 dB. This occurs when the Chilean earth station transmitter is at the test point with latitude -17.6 degrees and longitude -70.0 degrees. The worst single-entry interference values on the up link from every administration are listed in Table 4.3. The table also includes the test point in the interfering administration's service area which provides the worst interference.

4.4 Example 2

This case involves 6 satellites interfering with a Mexican satellite at $-110°$ W . Three of the satellites have service areas consisting of the continental United States and the 3 others serve Canada, Ecuador, and Nicaragua. $\Delta\phi$ values are calculated using the "DELTA" required separation computer program with the standard FSS

Table 4.2: Down-link, single-entry interference values for Chile in example 1. The Chilean test point is located at (-23.0,-66.5).

Interfering Administration	Down-Link Single-Entry C/I (dB)
Paraguay	32.63
Bolivia	34.76
Argentina	37.58
Sur./Fre. Guiana	42.33
Ecuador	42.64
Uruguay	49.89
Aggregate Down-Link C/I	29.28(dB)

Table 4.3: Worst single-entry C/I ratios on the up link for the Chilean satellite in example 1. Chilean transmitter is located at (-17.6,-70.0).

Interfering Administration	Site of Worst Interfering Transmission (Latitude , Longitude)	Single-Entry Up Link C/I (dB)
Sur/Fre Guiana	2.1,-56.2	32.93
Bolivia	-22.7,-67.5	36.94
Ecuador	-2.0,-81.1	37.72
Argentina	-32.0,-70.4	38.28
Uruguay	-33.9,-58.4	40.85
Paraguay	-22.2,-62.7	41.65
Aggregate Up-Link C/I Value		29.22 dB

Table 4.4: Satellite locations for the aggregate interference calculations of example 2.

Administration	Satellite Location (Longitude)
USA 1	-103.82
USA 2	-106.91
Ecuador	-108.96
Mexico	-110.00
Canada	-111.28
Nicaragua	-112.24
USA 3	-114.59

elliptical pattern specified for both the transmitting and receiving antennas on the satellite. The standard earth antenna pattern described in Chapter 2 is used and a 4.5 m dish diameter is assumed for both the transmitting and receiving antennas on the ground. The single-entry C/I requirement is set to 25 dB to achieve aggregate interference levels of 20 dB or higher.

The orbital assignment scheme shown in Table 4.4, in which all single entry separation requirements are met, is considered.

An aggregate interference analysis for Mexico using "MISOUP" indicates that the resulting link aggregate C/I level is 19.70 dB. This is below the aggregate C/I allowance of 20 dB by 0.3 dB. The worst aggregate C/I ratio on the down link occurs at the Mexican test point with latitude 31.78 degrees and longitude -106.55 degrees and is 22.31 dB. The worst up-link interference occurs with the Mexican up-link transmitter test point at latitude 32.53 degrees and longitude -117.20 degrees and is 23.16 dB.

Table 4.5 shows the interference from each satellite on the down link at the worst test point in Mexico. Table 4.6 shows the worst interference on the up link from the

Table 4.5: Single-entry, down-link C/I values for the Mexican satellite in example 2. The Mexican test point is (31.78,-106.55).

Interfering Administration	Single-Entry Down-Link C/I (dB)
Canada	26.21
USA 2	26.76
USA 3	30.96
USA 1	34.33
Ecuador	37.51
Nicaragua	46.75
Aggregate Down-link C/I	22.31 dB

satellite networks of the other administrations. The main sources of interference on the down link come from Canada and the U.S. while the main source of interference on the up link is Nicaragua. Note that in this example, that the Mexican satellite has four neighboring satellites (Nicaragua, Canada, USA 2, and Ecuador) which are all located at the minimum spacing from it allowed by the single-entry requirement. This is possible because the Canadian and Nicaraguan satellites do not interfere very strongly with each other and neither do those from the U.S. and Ecuador.

4.4.1 Example 3

This example shows the negative effects of having many satellites clustered together due to required separation values that are all small or zero. The "fast rolloff" pattern described in Chapter 3 (Equation (3.2)) is used for the satellite transmitting antenna of all administrations as well as for the receiving pattern of all satellite antennas. The standard earth antenna pattern described in Chapter 2 is used and a 4.5 m dish diameter is assumed for both the transmitting and receiving antennas on the ground. The single-entry link C/I requirement is 36 dB.

Table 4.6: Worst single-entry up-link C/I values for the Mexican satellite of example 2. The location of the Mexican transmitter is (32.53,-117.20).

Interfering Administration	Site of Worst Interfering Transmission (Latitude , Longitude)	Single-Entry Up-Link C/I (dB)
Nicaragua	14.70, -84.80	27.74
USA 2	26.00, -97.20	29.76
Canada	48.30,-123.90	30.57
Ecuador	1.40, -78.90	31.97
USA 3	26.00, -97.20	34.03
USA 1	26.00, -97.20	37.30
Aggregate Up-link C/I		23.16 dB

Table 4.7 shows an arrangement of 8 satellites over 4.93 degrees of orbital arc where all single-entry separation requirements are met. Many of the pairs of these satellites can be located quite close together or collocated since their service areas are widely separated geographically and the "fast rolloff" patterns are being used.

The results from MISOUP for this distribution of satellites show that the link aggregate C/I for Paraguay is only 29.05 dB or nearly 7 dB below the single-entry requirement. The worst-case down-link aggregate C/I value is 32.37 dB at the test point at -27.2 degrees latitude and -56.2 degrees longitude. The worst-case aggregate C/I was 31.77 dB. The single-entry down-link C/I values at the worst test point are listed in Table 4.8. The worst single-entry up-link C/I values are listed in Table 4.9.

The following three examples are the result of runs made with the K-permutation algorithm. Each is a feasible solution to some orbital assignment problem for which the aggregate C/I goal is not met for every administration even though all of the

Table 4.7: Satellite locations for aggregate interference calculations of example 3.

Administration	Satellite Location (Longitude)
Peru	-36.91
Paraguay	-36.00
Costa Rica	-36.00
Virgin Islands	-36.00
Quebec	-36.00
Falkland Islands	-35.52
Grenada	-34.79
Uruguay	-31.98

Table 4.8: Single-entry down-link C/I values for Paraguay at (-27.2,-56.2) in example 3.

Interfering Administration	Single-Entry Down-Link C/I (dB)
Peru	36.99
Uruguay	37.62
Quebec	39.03
Falkland Is.	44.63
Costa Rica	45.78
Virgin Is.	47.04
Grenada	63.35
Aggregate Down-Link C/I	32.37 dB

Table 4.9: Worst single-entry up-link C/I values for each interferer in example 3. The transmitter in Paraguay is located at (-20.5,-62.2).

Interfering Administration	Site of Worst Interfering Transmission (Latitude , Longitude)	Up-Link C/I (dB)
Falkland Is.	(-51.0,-61.5)	37.67
Costa Rica	(8.1,-82.9)	38.52
Virgin Is.	(18.7,-64.3)	39.22
Quebec	(51.0,-67.0)	39.22
Uruguay	(-30.1,-56.9)	40.68
Peru	(-18.3,-70.4)	45.78
Grenada	(12.6,-61.7)	60.57
Aggregate Up-Link C/I		31.77 dB

single-entry requirements are satisfied. For each example, the system parameters used to generate the required separation constraints are listed. These are followed by a listing of a solution obtained from the K-permutation algorithm. The solution lists the orbital location of every satellite, the worst-case down-link aggregate C/I, the worst-case up-link aggregate C/I, and the worst-case link aggregate C/I.

4.4.2 Example 4

This example involved 14 administrations in South America including 3 Brazilian satellites. For the transmitting pattern of all satellite antennas the "fast rolloff" pattern (Equation (3.2)) is used. For the receiving pattern of all satellite antennas the standard FSS elliptical pattern is used. The standard earth station pattern described in Chapter 2 is used for all administrations and a dish diameter of 4.5 m is assumed. The single-entry C/I requirement is 32 dB; thus the goal for the aggregate C/I values using the 5 dB margin is 27 dB. The objective function used is to

Table 4.10: Solution for example 4: South American scenario with a single-entry requirement of 32 dB.

Administration	Sat. Loc. (Longitude)	Worst Up-Link C/I (dB)	Worst Down-Link C/I (dB)	Worst Link C/I (dB)
Brazil 1	-44.95	36.67	34.80	32.62
Brazil 2	-50.69	33.63	31.83	29.63
Brazil 3	-56.43	31.12	31.36	28.23
Surin. Fre. Guyana	-61.81	31.08	29.44	27.17
Chile	-62.57	28.00	32.93	26.79
Columbia	-64.42	28.11	34.21	27.16
Paraguay	-65.28	28.34	30.51	26.28
Guyana	-66.05	29.50	30.87	27.13
Uruguay	-68.48	35.67	33.72	31.58
Bolivia	-70.85	29.32	33.77	27.99
Venezuala	-71.86	31.74	33.28	29.43
Argentina	-78.05	33.50	36.27	31.66
Peru	-80.88	32.35	36.74	31.00
Ecuador	-88.05	40.09	37.14	35.36

minimize the maximum deviation from a desired location. For each administration the desired location is defined to be the center of its feasible arc with a minimum elevation angle of 10 degrees. The best solution obtained to the problem is listed in Table 4.10, along with the resulting aggregate C/I levels.

Note that two administrations, Chile and Paraguay, have link C/I values below the goal of 27 dB. For both administrations the aggregate interference is worse on the up link than on the down link. Actually, for a small scenario like this, only those administrations whose satellites end up in the center of the arc will have trouble since these have the most potential interferers.

4.4.3 Example 5

This example involves 29 satellites in North and South America. Again the single-entry requirement is 32 dB with an aggregate goal of 27 dB. The "fast rolloff" pattern (Equation (3.2)) is used for the transmitting antennas of all of the satellites with the standard FSS receiving pattern for the receiving antennas. The standard earth station pattern described in Chapter 2 is used for all administrations and a dish diameter of 4.5 m is assumed. The objective function is to minimize the total deviation of all satellites from their desired locations. The maximum required separation values over the entire arc (ΔS values) are used in this example, thus the solution is a conservative one in which the distance between the orbital locations of adjacent satellites generally exceeds the minimum required to meet the limit on single-entry interference. Two U.S. administrations, however, still do not meet the goal of 27 dB for the link aggregate C/I ratio. All of the other administrations have very good levels of aggregate interference except Columbia which only slightly exceeds the goal. The results are summarized in Table 4.11.

4.4.4 Example 6

This scenario involves 41 satellites in North and South America. The single-entry C/I requirement is 25 dB with an aggregate C/I goal of 20 dB. The standard FSS elliptical pattern is used for both the satellite transmitting and receiving patterns on all satellites. The standard earth station pattern described in Chapter 2 is used for all administrations and a dish diameter of 4.5 m is assumed. Location-dependent separation values are used in this example. The results are summarized in Table 4.12. Note that 6 satellites do not quite meet the goal of 20 dB although

Table 4.11: Solution and the aggregate C/I ratios for example 5.

Administration	Sat. Loc. (Longitude)	Worst Up-Link C/I (dB)	Worst Down-Link C/I (dB)	Worst Link C/I (dB)
Brazil	-44.25	37.56	34.93	33.04
Surinam and French Guiana	-50.17	35.60	32.87	31.01
Guyana	-56.30	34.53	36.29	32.31
Paraguay	-57.58	35.80	33.63	31.57
Caribbean	-60.46	32.57	34.70	30.49
Bolivia	-63.39	30.84	34.92	29.41
Uruguay	-65.51	38.17	40.84	36.29
USA 1	-66.65	30.94	31.87	28.37
Venezuela	-68.31	33.35	34.20	30.74
Chile	-69.84	31.39	33.18	29.18
USA 2	-73.07	30.70	32.71	28.58
Columbia	-75.00	28.37	33.95	27.31
Argentina	-76.29	33.78	33.99	30.87
Cuba	-78.56	33.86	32.04	29.84
Ecuador	-80.74	33.50	32.24	29.81
Costa Rica	-82.17	34.90	34.79	31.83
USA 3	-83.65	27.60	30.54	25.82
Honduras	-86.00	33.34	34.34	30.80
Peru	-87.41	31.40	33.82	29.43
USA 4	-88.35	27.97	29.68	25.73
Nicaragua	-91.94	35.77	33.73	31.62
USA 5	-94.38	30.35	31.87	28.04
Mexico 1	-100.37	30.86	31.64	28.22
Canada 1	-102.18	30.38	33.14	28.53
Mexico 2	-106.60	31.29	33.41	29.21
Canada 2	-108.40	30.62	32.06	28.27
USA 6	-114.90	33.22	30.89	28.89
USA 7	-120.93	34.06	31.28	29.44
USA 8	-140.96	36.97	34.30	32.42

they may come near enough for practical purposes. The lowest link aggregate C/I value is the one for Cuba of 19.28 dB. Missing the aggregate goal by only 0.72 dB for the worst satellite is still a promising result considering there are 41 satellites in this scenario.

4.5 Discussion of the Aggregate Interference Problem

While the 5 dB margin between the single-entry C/I requirement specified for the required separation calculations and the aggregate C/I goal will not be sufficient in every case, it is still a reasonable first estimate for many scenarios. There are situations, however, for which this margin will be exceeded and these become more frequent as satellites are packed closer together to maximize use of the orbit. One important criterion that will be used to judge whether or not a given solution to the orbital assignment problem is acceptable is the set of aggregate C/I values obtained for all administrations. Some thought must be given as to how to modify the search procedure if a problem develops in satisfying the aggregate C/I requirement.

There are several potential ways to handle this problem. If many feasible solutions to a given problem were available, then an aggregate C/I analysis of each could be done to help determine which ones were acceptable. A feasible solution is defined as one which meets two criteria. First, all administrations receive an orbital location within a portion of the GSO visible from all sites in their service areas with at least some minimum elevation angle. Secondly, all single-entry C/I requirements are satisfied. An acceptable solution requires that every administration has a link aggregate C/I ratio above some stated goal. Furthermore, such a study could be

Table 4.12: Solution and aggregate C/I values for example 6.

Administration	Sat. Loc. (Longitude)	Worst Up-Link C/I (dB)	Worst Down-Link C/I (dB)	Worst Link C/I (dB)
Brazil 1	-44.93	28.24	26.53	24.29
Brazil 2	-47.81	25.80	23.73	21.63
Surinam and French Guiana 1	-50.64	23.10	26.63	21.50
Brazil 3	-53.47	24.86	23.32	21.01
Surinam and French Guiana 2	-56.30	27.70	22.14	21.08
Caribbean	-57.95	23.15	25.53	21.17
Paraguay	-59.27	27.69	21.28	20.39
Guyana	-60.08	26.91	20.98	19.99
Cuba	-60.88	26.72	20.14	19.28
Bolivia	-61.67	23.44	25.16	21.21
Uruguay	-62.91	33.15	21.48	21.20
USA 1	-63.71	25.27	23.72	21.42
Chile	-65.78	26.52	24.64	22.47
USA 2	-66.81	24.71	21.83	20.02
Venezuela	-68.14	29.70	24.03	22.99
Argentina	-69.03	26.35	21.56	20.32
USA 3	-69.91	24.87	21.43	19.81
Peru	-71.64	26.30	25.34	22.78
USA 4	-73.01	24.76	22.18	20.27
Columbia	-74.48	24.18	24.92	21.52
USA 5	-76.45	25.31	23.26	25.31
Ecuador	-78.00	30.51	27.33	25.62
USA 6	-79.55	23.64	23.22	20.42
Nicaragua	-80.91	28.38	22.51	21.51
USA 7	-82.61	23.42	23.00	20.20
Costa Rica	-83.80	29.15	22,72	21.83
USA 8	-85.64	23.28	23.24	20.25
Honduras	-87.18	32.83	21.65	21.33
USA 9	-88.72	23.54	23.13	20.32
USA 10	-91.73	25.41	23.21	21.16
USA 11	-94.74	25.49	23.13	21.14
USA 12	-97.75	25.58	23.15	21.19
USA 13	-100.75	25.51	23.26	21.23
USA 14	-103.75	25.26	23.24	21.12
USA 15	-106.75	24.70	23.54	21.07
Mexico 1	-109.84	24.32	21.32	19.55
Canada 1	-111.12	24.08	22.20	20.03
Mexico 2	-112.74	24.09	21.62	19.67
Canada 2	-114.32	23.37	21.64	19.41
Mexico 3	-115.64	25.20	21.96	20.27
Canada 3	-117.11	25.40	24.20	21.75

used to decide which solution was the best in some sense. The best solution could be defined in many ways. One definition would be to define it as the one for which the lowest link aggregate C/I ratio for an individual administration was maximized. A second would be to define it as one for which the difference between the greatest and least link aggregate C/I levels for individual administrations was minimized.

For a large and difficult scenario, many feasible solutions might not be available. Even if several such solutions were available, then each one might have a few administrations for which the link aggregate C/I goal was not reached. In such cases, it would be necessary to increase the margin between single-entry C/I levels and the aggregate goal. The new margin could be set at 6 or 7 dB perhaps. Naturally, this could make the task of finding such solutions more difficult. It would also make the solution to the orbital assignment problem into an iterative process. The required separation constraints would first be calculated assuming a 5 dB margin between the single-entry requirement and the aggregate C/I goal. The K-permutation algorithm would be run to determine feasible solutions. If no solution were found for which a satisfactory aggregate C/I value was obtained for all administrations, then the margin between the single-entry requirement and the aggregate C/I goal would be raised and the separation constraints recalculated. This would continue until a suitable solution was found.

If the margin between the required single-entry C/I ratio and the desired aggregate C/I were raised, the amount of extra satellite separation required would be determined by the ground station antenna reference pattern. For the ground station antenna pattern reported in Chapter 2, the relative gain in the sidelobes is determined from $(29 - G) - 25\log(\theta)$, where θ is the topocentric off-axis angle measured at the ground station and G is the on-axis gain of the antenna. Suppose

that the amount of earth discrimination needed on either the up link or the down link is equal to a constant K. Thus K is given by

$$K = (29 - G) - 25\log(\theta_1). \tag{4.2}$$

The off-axis angle, θ_1, needed to provide the discrimination is

$$\theta_1 = 10^{-(\frac{29-G-K}{25})}. \tag{4.3}$$

Now, if the amount of discrimination provided by the earth station antenna needs to be lowered by 1 dB to satisfy the new margin, the required separation can be found from

$$K - 1 = (29 - G) - 25\log(\theta_2), \tag{4.4}$$

and

$$\theta_2 = 10^{\left(-\frac{29-G-K+1}{25}\right)}. \tag{4.5}$$

Thus the relationship between the off-axis angle required to get the additional discrimination and the original off-axis angle is

$$\theta_2 = \left(\frac{10^{30/25}}{10^{29/25}}\right), \tag{4.6}$$

so that,

$$\theta_2 = 1.096\theta_1. \tag{4.7}$$

The resulting increase in required topocentric angle is approximately 10%. The required increase in longitudinal spacing would be approximately the same.

The assumption that the interfering satellite is in the sidelobes of the ground station antenna is valid when the original required separation value is large. If it is

not, then the additional required separation might be more or less than the figure stated above.

In some cases it might be possible to increase the margin, not for all administrations, but only for those where the aggregate C/I ratio was not satisfactory in any solution. Thus, only the separation constraints which affected the particular administrations with low C/I values would be increased. In this way, the task of finding new solutions would not be as difficult as it would if all separation constraints had to be increased. This would require some changes to the required separation program, "DELTA", however. It would now require an array of single-entry C/I requirements rather than just a single value which applies to all administrations. These changes would not be difficult, however.

Chapter 5

Conclusions

The purpose of this study has been to examine several areas pertaining to the "Delta-S" method of solving the orbital assignment problem for the FSS. This method involves calculating pairwise separation requirements to use in linear constraints on the orbital assignments. These are calculated by finding the minimum required separation between two satellites that satisfies a specified single-entry C/I ratio at a given location in the GSO. By limiting the single-entry interference to acceptable levels, it is assumed that the aggregate C/I requirement will be met for all administrations as well. Thus a suitable margin must be allowed between the single-entry C/I requirement and the permissable level of aggregate interference.

In Section 2, the required separation calculations are extended to include up-link as well as down-link interference. The procedure for incorporating up-link interference into the calculations is relatively simple and is analogous to the procedure used on the down link. A new computer program to compute the required separation values is introduced which incorporates both the up link and the down link. This program is not significantly more complex than the previous program as many of the angle and range calculations can be used in both the down-link and up-link

equations. Since the amount of computer time needed to generate the required separation values is small compared to the time required to solve the orbital allotment problem, the small increase in this time needed to include the up link is not significant. While for the BSS case the up link could be disregarded, this is not possible for the FSS case since significant levels of interference can be present on both the up link and the down link. Thus the inclusion of up-link interference into the required separation calculations seems to be a sensible extension of the original computer program.

In Section 3, a preliminary study is made of various methods for modelling the gain of shaped-beam satellite antennas in regions outside the satellite's service area. All of the methods discussed are based on heuristic reasoning and, as of yet, have not been compared to actual data from operational or proposed satellites.

One of the methods discussed is a modification of an elliptical pattern. The loci of constant directivity for this pattern are no longer ellipses outside the minimum ellipse enclosing the service area. Use of this pattern results in a dramatic improvement in the amount of interference power presented to areas outside the service area of the satellite. The effects of using this pattern in place of the standard elliptical pattern in required separation calculations is discussed. When it is used for both the transmitting and receiving antennas of the satellite, the amount of required separation for the satellites of administrations that do not have adjacent service areas is greatly reduced. For the satellites of administrations with adjacent service areas there is no reduction in required separation.

Another attempt to model the effects of shaped beams assumes that a service area will be covered by n circular sub-beams of a constant radius. The service area to be covered is represented by a polygon in the plane orthogonal to the antenna

axis and the circular sub-beams are placed within this in such a manner as to cover the polygon with a sensible number of beams. This is a very subjective method which involves a certain amount of trial and error. It has been used to offset the lack of data from operational satellites. While it would not be practical to use for the required separation calculations, it provides interesting data which can be compared with the results of the other methods.

Two other methods are presented which attempt to predict the gain pattern of the shaped beam based on the geometrical shape of the service area. Both of these methods represent the service area by a polygon in a plane orthogonal to the axis of the antenna. This polygon represents the -3 dB contour. In one, the gain outside the contour is determined solely from the distance from the boundary of the polygon and the gain falls off uniformly from the -3 dB contour. In the second, a line is extended from the point at which the gain is being tested through the aimpoint of the antenna and across the polygon. The distance across the polygon between the two points on it that this line intersects is measured. A second distance is measured from the point being tested to the point at which the line through the aimpoint first hits the -3 dB contour. These two distances are then used to determine the gain.

The uniform rolloff method is extremely simple both conceptually and computationally. It may be a reasonable method of estimating the relative gain of a shaped-beam antenna outside its service area, but the conditions of such validity have yet to be demonstrated. More work needs to be done on the application of this method. Incorporating a simple model like this into the required separation program would not be a difficult task. If actual data from operational or proposed satellites were available, the rate of gain rolloff from the edge of the polygon could be adjusted to more closely reflect this data. This method and the "projection

through center" method could, perhaps, be combined to produce a model with a rate of rolloff decided both by the dimension of the sub-beams and the width of the service area.

In Section 4, the aggregate C/I problem is discussed. A new computer program, "MISOUP", to analyze the aggregate interference for a distribution of satellites is introduced which includes the effects of interference on both the up link and the down link into a total link aggregate C/I value. The 5 dB margin between the single-entry C/I requirement and the desired aggregate C/I ratio is shown to be a reasonable first estimate. It is not sufficient in all cases, however.

Two potential solutions to the problem of satisfying the aggregate C/I criterion in solutions to linear and mixed-integer programs that only consider single-entry interference are proposed. One is that an aggregate C/I analysis be used as one of the criteria, in addition to visible arc constraints and single-entry C/I requirements for deciding whether a given solution is acceptable or not. Given a large number of feasible solutions from the K-permutation algorithm, the link aggregate C/I values could be used in addition to the objective function values of the solutions to help decide which solutions were desirable. The second is to raise the 5 dB margin, either for all administrations or for just those which do not receive good aggregate C/I values for any solution found.

More work needs to be done on this area, particularly with large scenarios. It is not clear for an 80 satellite scenario, for example, how many feasible solutions will be found and what sort of link aggregate C/I values will be obtained. Nor is it clear how serious the effects of increasing the margin between the single-entry requirements and the aggregate C/I goal will be. If an ample number of solutions can be found when a margin of 6 or 7 dB is used for all satellites then this problem

may not be significant.

Appendix A

Multiple-Channel Calculations

The calculations of Section 2 consider only co-channel interference between two satellite networks in determining the required separation. For the BSS problem, the Final Acts of WARC (ORB-85) [21] recommend a procedure that includes interference from the four nearest channels of an interfering satellite in addition to the co-channel interference. It is not clear what methods will be adopted in future conferences for the FSS, however a similar approach might be taken. Thus, the purpose of this appendix is to briefly explain the BSS approach and to describe how it might be included in the calculations of Section 1.

The BSS method requires the specification of protection ratios for the desired channel of a satellite for all significant interfering channels. The protection ratios represent the minimum tolerable ratio of received carrier power to the interfering power present on a given interfering channel. These can be defined on a single-entry or an aggregate interference basis. They are designated by the symbol, PR. A channel margin, M, is also defined. The channel margin, for a given interfering channel, is the difference in decibels between the ratio of the received carrier power to the received interference power on this channel (C/I) and the channel protection

ratio. Thus a channel margin of 0 dB would mean that the interference of that particular channel would be sufficient by itself to reduce the C/I ratio in the desired channel to the minimum satisfactory value. In general, channel margins are greater than zero to allow for interference contributions from several interfering channels.

In the total interference calculations, the first adjacent upper and lower interfering channels and second adjacent upper and lower interfering channels are included in addition to the interfering channel with the same carrier frequency as the desired channel. The interference power present on these channels is used to determine an overall equivalent protection margin, M, which is given by the expression

$$M = -10\log[\sum_{i=1}^{n} 10^{-M_i/10}], \tag{A.1}$$

where

1. M_1 = overall co-channel protection margin.
2. M_2 = overall adjacent channel protection margin for the upper adjacent channel.
3. M_3 = overall adjacent channel protection margin for the lower adjacent channel.
4. M_4 = overall second adjacent channel protection margin for the upper second adjacent channel.
5. M_5 = overall second adjacent channel protection margin for the lower second adjacent channel.

An equivalent protection margin greater than zero indicates an acceptable level of interference.

Generally, a protection ratio template is supplied which gives the protection ratio needed relative to the co-channel protection ratio. This is specified as a function of the frequency offset between the desired carrier and the interfering signal. In principle, this template might depend on the signal charateristics of both the desired and interfering signals, i.e., on the type of information being transmitted and the modulation schemes employed. In practice, if this information is not available, it might be useful to define a "worst-case" template to use in these calculations. An example of such a template is shown in Figure A.1 [24].

It will not be a difficult matter to extend the required separation calculations of Section 2 to include multiple-channel interference. Consider the up-link interference equation, Equation (2.3),

$$(C/I)_{up} = \frac{P_1 G_{ET1} D_{SR1}(\psi, \psi_o)(4\pi L_2)^2 Y_u}{P_2 G_{ET2} D_{ET2}(\theta, \theta_o) D_{SR1}(\alpha, \alpha_o)(4\pi L_1)^2 M_u}. \tag{A.2}$$

Note that for different interfering up-link channels from the same location in the same service area, the only factors that will change in the interference power calculation would be the wavelength, λ, and the polarization discrimination factor, Y_u, if polarization discriminations are specified. The same is true for the down-link calculations. Thus, the co-channel calculations need be done only for a typical channel in the center of the frequency band considered.

Now, considering the procedure outlined in Section 2 for the program "DELTA", a modified search procedure for finding the required separation between two satellites for a specified mean orbital location is as follows:

1. Space the satellites by the trial solution.

2. Calculate the down-link, single-entry equivalent protection margin at each test

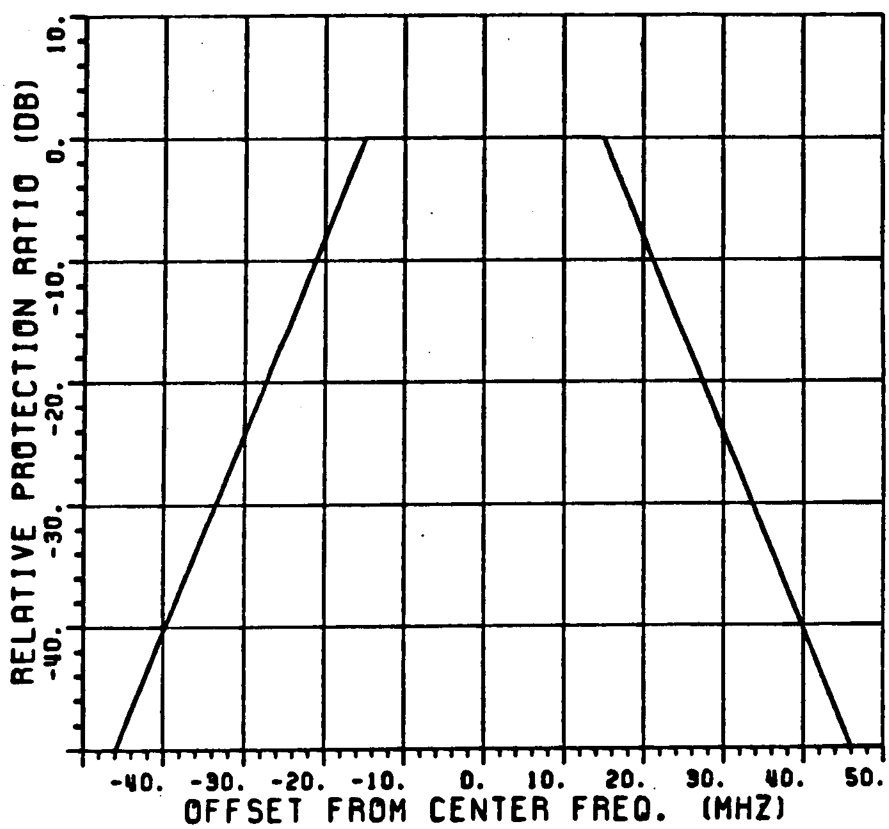

Figure A.1: Sample protection ratio template.

point for a typical channel in the center of the frequency band considered. For each test point:

   (a) Calculate the down-link co-channel C/I as before for the test point being considered.

   (b) Calculate the single-entry down-link equivalent protection margin from Equation (A.1) for the test point being considered.

3. Select the worst down-link, single-entry margin so calculated.

4. Calculate the up-link, single-entry equivalent protection margin at each interfering ground station test point for a typical channel in the center of the frequency band considered. For each test point:

   (a) Calculate the up-link co-channel C/I as before for the test point being considered.

   (b) Calculate the single-entry up-link equivalent protection margin from Equation (A.1) for the test point being considered.

5. Select the worst up-link, single-entry margin so calculated.

6. Combine the worst up-link and down-link margins to obtain a worst single-entry link protection margin.

7. Compare the worst single-entry link protection margin to the required margin (5 dB perhaps, to allow for a 0 dB aggregate margin).

8. If the spacing is satisfactory, save the current trial solution as the value for $\Delta\phi$. If not, then determine a new trial solution as before. Repeat the process

from step one.

Appendix B

DELTA: FORTRAN Program to Calculate Required Separation Values

```
C
C                    >>  MAIN PROGRAM  <<
C
C     THIS IS A MODIFICATION OF C.W. WANG'S DELTA S PROGRAM (1985)
C     TO CALCULATE THE MINIMUM SATELLITE SEPARATION. THIS
C     PROGRAM TREATS BOTH THE UPLINK AND THE DOWNLINK.
C     THE CALCULATIONS ARE BASED ON CCIR REP-455 AND SOUP-3.
C     THE MODIFICATIONS WERE MADE BY P. KOHNHORST AND P. BHASIN
C     IN 1986-1987.
C
C     THIS PROGRAM CONSISTS OF TWO MAIN BLOCKS. THE INNER BLOCK
C     CALCULATES THE MINIMUM REQUIRED LONGITUDINAL SPACING FOR
C     A PAIR OF SATELLITES AT A SPECIFIED ORBITAL LOCATION.
C     THE SECOND BLOCK IS BUILT AROUND THIS. THIS BLOCK INPUTS THE
C     REQUIRED INFORMATION ON EACH SATELLITE ADMINISTRATION, SETS UP
C     THE LOOPS TO CALCULATE REQUIRED SEPARATION VALUES FOR ALL PAIRS
C     OF SATELLITES AT EVERY ORBITAL LOCATION SPECIFIED, AND WRITES
C     THE OUTPUT FILES.
C
C***********************VARIABLE LIST******************************
C
C>>>>>>>>>>>>>>>>>>>CONSTANTS TO BE INPUT<<<<<<<<<<<<<<<<<<<<<<<<<<<<
C
C      OPTION----SPECIFIES 1 OF 2 POSSIBLE OUTPUT FILE OPTIONS
C
C          OPTION=1------CALCULATES DELTA-PHIS OVER FEASIBLE ARC AT
C                        INCREMENTS SPECIFIED BY INTSP. OUTPUT IS
C                        LISTING FOUND IN FILE OUTFILE + DELTA-S
C                        MATRIX
C
C          OPTION=2------CALCULATES DELTA-PHIS OVER FEASIBLE ARC
C                        ONLY AT LOCATIONS SPECIFIED BY FILE
C                        SATLOC. WRITES DELTA-PHI AND DELTA-S
C                        MATRICES + OUTFILE
C
C      COIMIN----MINIMUM ALLOWED TOTAL LINK SINGLE ENTRY CARRIER TO
C                INTERFERENCE RATIO
C      INTSP-----INCREMENT BETWEEN CALCULATED ELLIPSES
C      NUMSAR----NUMBER OF SERVICE AREAS IN MATRIX
C      UFREQ-----FREQUENCY IN GHz AT WHICH UPLINK CALCULATIONS ARE
C                PERFORMED
C      DFREQ-----FREQUENCY IN GHz AT WHICH DOWNLINK CALCULATIONS ARE
C                PERFORMED
C
C>>>INPUT ARRAYS CONTAINING INFORMATION ON ALL OF THE ADMINISTRATIONS<<<<<<
C
C       SANAME---ARRAY OF SERVICE AREA NAMES
C       NUMSAT---NUMBER OF ADMINISTRATIONS WHICH HAVE THE SAME SERVICE
C                AREA AS THIS ADMINISTRATION. NORMALLY THIS IS 1.
C
C       INTP-----NUMBER OF TEST POINTS IN THIS ADMINISTRATION
C       ADELAT---ARRAY OF TEST POINT LATITUDES IN DEGREES
C       ADELON---ARRAY OF TEST POINT LONGITUDES IN DEGREES
C
C       ADT------CONTAINS DIAMETERS OF EARTH STATION TRANSMITTING
C                ANTENNAS
C       ADR------CONTAINS DIAMETERS OF EARTH STATION RECEIVING
C                ANTENNAS
C
C       APTNER---INTEGER ARRAY CONTAINING THE NUMBER OF THE REFERENCE
C                PATTERN USED FOR THE EARTH STATION RECEIVING ANTENNA
C                FOR EACH ADMINISTRATION
C       APTNET---INTEGER ARRAY CONTAINING THE NUMBER OF THE REFERENCE
C                PATTERN USED FOR THE EARTH STATION TRANSMITTING
C                ANTENNA FOR EACH ADMINISTRATION
C       APTNST---INTEGER ARRAY CONTAINING THE NUMBER OF THE REFERENCE
```

```
C               PATTERN USED FOR THE SATELLITE TRANSMITTING ANTENNA
C               FOR EACH ADMINISTRATION
C       APTNSR---INTEGER ARRAY CONTAINING THE NUMBER OF THE REFERENCE
C               PATTERN USED FOR THE SATELLITE RECEIVING ANTENNA
C               FOR EACH ADMINISTRATION
C
C       NELLOC----ARRAY CONTAINING NUMBER OF ORBITAL LOCATIONS FOR WHICH
C                MINIMUM ELLIPSES HAVE BEEN CALCULATED FOR EACH
C                ADMINISTRATION
C       WELLOC----ARRAY CONTAINING WESTERN-MOST ORBITAL LOCATION FOR WHICH
C                A MINIMUM ELLIPSE BEEN CALCULATED FOR EACH ADMINISTRATION
C       EELLOC----ARRAY CONTAINING EASTERN-MOST ORBITAL LOCATION FOR WHICH
C                A MINIMUM ELLIPSE BEEN CALCULATED FOR EACH ADMINISTRATION
C
C       AELLOC----CONTAINS SATELLITE LOCATIONS FOR MINIMUM ELLIPSES
C       ADBLAT----CONTAINS AIMPOINT LATITUDES FOR MINIMUM ELLIPSES (DEGREES)
C       ADBLON----CONTAINS AIMPOINT LONGITUDES FOR MINIMUM ELLIPSES (DEGREES)
C       AORENT----CONTAINS ORIENTATION ANGLES FOR MINIMUM ELLIPSES (DEGREES)
C       AAXMAJ----CONTAINS MAJOR AXIS DATA FOR ELLIPSES (DEGREES)
C       AAXMIN----CONTAINS MINOR AXIS DATA FOR ELLIPSES (DEGREES)
C
C>>>>>>>>>    2 ELEMENT ARRAYS USED IN THE INNER BLOCK    <<<<<<<<<<<<
C      NAMESA----NAME OF ADMINISTRATION
C      NTPSA-----NUMBER OF TEST POINTS IN SERVICE AREA OF ADMINISTRATION
C      DELAT-----ARRAY OF TEST POINT LATITUDES IN DEGREES
C      DELON-----ARRAY OF TEST POINT LONGITUDES IN DEGREES
C      DT------CONTAINS DIAMETERS OF EARTH STATION TRANSMITTING
C              ANTENNAS
C      DR------CONTAINS DIAMETERS OF EARTH STATION RECEIVING
C              ANTENNAS
C
C      IPTNER---INTEGER ARRAY CONTAINING THE NUMBERS OF THE REFERENCE
C              PATTERNS USED FOR THE EARTH STATION RECEIVING ANTENNAS
C      IPTNET---INTEGER ARRAY CONTAINING THE NUMBERS OF THE REFERENCE
C              PATTERNS USED FOR THE EARTH STATION TRANSMITTING
C              ANTENNAS
C      IPTNST---INTEGER ARRAY CONTAINING THE NUMBERS OF THE REFERENCE
C              PATTERNS USED FOR THE SATELLITE TRANSMITTING ANTENNAS
C      IPTNSR---INTEGER ARRAY CONTAINING THE NUMBERS OF THE REFERENCE
C              PATTERNS USED FOR THE SATELLITE RECEIVING ANTENNAS
C
C      DBCLAT----AIMPOINT LATITUDE OF TRANSMITTING ANTENNA
C      DBCLON----AIMPOINT LONGITUDE OF TRANSMITTING ANTENNA
C      ORIENT----ORIENTATION ANGLE OF ELLIPTICAL BEAM
C      AXMAJ-----MAJOR AXIS OF ELLIPTICAL BEAM
C      AXMIN-----MINOR AXIS OF ELLIPTICAL BEAM
C
C>>>>>>>>>>>>>>>>>>>>>>>>>      RESULTS     <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
C
C      DELP(I,K,J)----DELTA-PHI VALUE AT ORBITAL LOCATION I FOR
C                     ADMINISTRATIONS K AND J
C
C      DELM(I,K)------DELTA-S VALUE FOR ADMINISTRATIONS I AND K
C
C      DELS ----------REQUIRED SEPARATION VALUE IN DEGREES OF LONGITUDE
C                     OUTPUT OF INNER BLOCK OF PROGRAM
C
C     ************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C ************************************************************
C
C     FILE 5, IS THE INPUT FILE
C     FILE 6 IS A LISTING OF SATELLITE LOCATIONS AND REQUIRED
C                SEPARATION VALUES
C     FILE 7 IS THE DELTA-S MATRIX
C     FILE 8 IS THE INPUT FILE OF SATELLITE LOCATIONS AT WHICH REQUIRED
C            SEPARATION VALUES ARE TO BE CALCULATED
C     FILE 10 IS THE DELTA-PHI MATRIX
C
      OPEN (UNIT=5,FILE='INPUT.DAT',TYPE='OLD')
      OPEN (UNIT=6,FILE='OUTFILE.DAT',TYPE='NEW')
      OPEN (UNIT=7,FILE='MATRIX1.DAT',TYPE='NEW')
      OPEN (UNIT=8,FILE='SATLOC.DAT',TYPE='OLD')
      OPEN (UNIT=10,FILE='MATRIX2.DAT',TYPE='NEW')
C
      CALL ICONST
      CALL INDATA
C
C          IF OPTION 2, READ SATELLITE LOCATIONS AT WHICH TO CALCULATE
C                             DELTA-PHIS
C
      IF (OPTION .EQ. 2) THEN
           READ(8,10) IPOS
```

Program DELTA (cont.)

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```
 10       FORMAT(I5)
          READ(8,20) (DELPOS(K), K=1,IPOS)
 20       FORMAT(6F10.2)
      END IF
C
C     THIS IS THE MAIN LOOP OF THE PROGRAM WHICH FINDS DELTA-PHI
C     VALUES BETWEEN ALL PAIRS OF ADMINISTRATIONS
C
      WRITE(6,11)COIMIN
 11   FORMAT(2X,'REQUIRED SEPARATION VALUES FOR LINK C/I REQUIREMENT
     1 OF',2X,F7.2,' dB')
      DO 1000         NS1=1,NUMSAR-1
            J=NS1+1
            DO 900 NS2=J,NUMSAR
            DELS=3.0
C
            NAMESA(1)=SANAME(NS1)
            NAMESA(2)=SANAME(NS2)
C
C    DETERMINE INTERSECTION OF FEASIBLE ARCS FOR TWO ADMINISTRATIONS
C
              E1=EELLOC(NS1)
              W1=WELLOC(NS1)
              E2=EELLOC(NS2)
              W2=WELLOC(NS2)
C
C  THE FIRST CASE IS WHERE THERE IS NO OVERLAP OF THE TWO FEASIBLE
C  ARCS BUT THE EASTERN ENDPOINT OF AREA 1 IS THE WESTERN ENDPOINT OF
C  AREA 2. FOR THIS CASE, REQUIRED SEPARATION VALUES ARE COMPUTED AT THAT
C  POINT AND FOR THE CLOSEST POINT IN THE ARC OF 1 TO THE WEST OF THAT
C  ENDPOINT AND THE CLOSEST POINT IN THE ARC OF 2 TO THE EAST OF THE
C  ENDPOINT.
C
               IF (E1 .EQ. W2) THEN
                  IFIR=(W2*(-1.))-2.0
                  ISEC=(E1*(-1.))+2.0
               ELSE
C
C  THIS HANDLES THE CASE WHERE THE INTERSECTION OF THE TWO ARCS
C  IS BETWEEN THE WESTERN EDGE OF THE ARC OF AREA 2 AND THE EASTERN
C  EDGE OF THE ARC OF AREA 1.
C
               IF ( ((W1 .LE. W2) .AND. (E1 .GE. W2)) .AND.
     1            (E1 .LE. E2) ) THEN
                  IFIR=(E1*(-1.))
                  ISEC=(W2*(-1.))
               ELSE
C
C  THIS HANDLES THE CASE WHERE THE ARC OF AREA 1 INCLUDES THE ENTIRE
C  ARC OF AREA 2. THE INTERSECTION IS JUST THE ARC OF 2.
C
               IF ( (W1 .LE. W2) .AND. (E2 .LE. E1) ) THEN
                  IFIR=(E2*(-1.))
                  ISEC=(W2*(-1.))
               ELSE
C
C  THIS HANDLES THE CASE WHERE THERE IS NO OVERLAP OF THE TWO
C  FEASIBLE ARCS BUT THE EASTERN ENDPOINT OF AREA 2 IS THE WESTERN
C  ENDPOINT OF AREA 1. FOR THIS CASE, REQUIRED SEPARATIONS ARE
C  COMPUTED AT THAT POINT AND FOR THE CLOSEST POINT IN THE ARC
C  OF 2 TO THE WEST OF THE ENDPOINT AND THE CLOSEST POINT IN THE
C  ARC OF 1 TO THE EAST OF THE ENDPOINT.
C
               IF (E2 .EQ. W1) THEN
                  IFIR=(W1*(-1.))-2.0
                  ISEC=(E2*(-1.))+2.0
```

```
              ELSE
C
C   THIS HANDLES THE CASE WHERE THE INTERSECTION OF THE TWO ARCS
C   IS BETWEEN THE WESTERN END OF THE ARC OF 1 AND THE EASTERN
C   END OF THE ARC OF 2.
C
              IF ( ((W2 .LE. W1) .AND. (E2 .GE. W1)) .AND.
     1           (E2 .LE. E1) ) THEN
                 IFIR=(E2*(-1.))
                 ISEC=(W1*(-1.))
              ELSE
C
C   THIS HANDLES THE CASE WHERE THE ARC OF 2 COMPLETELY CONTAINS
C   THE ARC OF 1. THE INTERSECTION OF THE 2 ARCS IS JUST THE
C   ARC OF 1.
C
              IF ( (W2 .LE. W1) .AND. (E1 .LE. E2) ) THEN
                 IFIR=(E1*(-1.))
                 ISEC=(W1*(-1.))
              ELSE
C
C   THERE IS NO INTERSECTION OF FEASIBLE ARCS. SET A FLAG TO INDICATE THIS
C
                 IFIR=-999
              END IF
              END IF
              END IF
              END IF
              END IF
              END IF
C
C    TRANSFER THE NEEDED INFORMATION ABOUT ADMINISTRATION 1 FROM THE
C    ARRAYS OF THE OUTER BLOCK OF THE PROGRAM TO THE ARRAYS OF THE INNER
C                              BLOCK
C
              DELM(NS1,NS2) = 0.0
              IPTNER(1)=APTNER(NS1)
              IPTNET(1)=APTNET(NS1)
              IPTNST(1)=APTNST(NS1)
              IPTNSR(1)=APTNSR(NS1)
              DT(1)=ADT(NS1)
              DR(1)=ADR(NS1)
              K=INTP(NS1)
              NTPSA(1)=K
C
              DO 850  I=1,K
                RELON(1,I)=RADIAN*ADELON(NS1,I)
                RELAT(1,I)=RADIAN*ADELAT(NS1,I)
 850          CONTINUE
C
C
C    TRANSFER THE NEEDED INFORMATION ABOUT ADMINISTRATION 2 FROM THE
C    ARRAYS OF THE OUTER BLOCK OF THE PROGRAM TO THE ARRAYS OF THE INNER
C                              BLOCK
C
              IPTNER(2)=APTNER(NS2)
              IPTNET(2)=APTNET(NS2)
              IPTNST(2)=APTNST(NS2)
              IPTNSR(2)=APTNSR(NS2)
              DT(2)=ADT(NS2)
              DR(2)=ADR(NS2)
              K=INTP(NS2)
              NTPSA(2)=K
C
              DO 860  I=1,K
                RELON(2,I)=RADIAN*ADELON(NS2,I)
```

```
                RELAT(2,I)=RADIAN*ADELAT(NS2,I)
 860          CONTINUE
C
C  IF THERE IS NO INTERSECTION OF THE FEASIBLE ARCS THEN CALL A
C                    SPECIAL SUBROUTINE
C
              IF (IFIR .EQ. -999) THEN
                     CALL NOINT(NS1,NS2,W1,E1,W2,E2)
                     GOTO 900
              END IF
C
C  THIS IS A LOOP OVER ALL OF THE ORBITAL LOCATIONS CONSIDERED
C  OVER THE FEASIBLE ARCS OF THE 2 ADMINISTRATIONS.
C
C  IF OPTION EQUALS 2 THEN THE SEPARATION VALUES ARE CALCULATED
C  AT THE LOCATIONS SPECIFIED IN THE ARRAY DELPOS. OTHERWISE
C  THEY ARE CALCULATED AT EQUALLY SPACED INCREMENTS OVER THE
C                      ENTIRE ARC
C
              IF (OPTION .EQ. 1) THEN
                 NP1=IFIR
                 NP2=ISEC
                 NP3=INTSP
              ELSE
                 NP1=1
                 NP2=IPOS
                 NP3=1
              END IF
C
              DO 800 NPOS= NP1, NP2, NP3
                  IF (OPTION .EQ. 1) THEN
                     SLON=(-1.0)*DBLE(NPOS)
                  ELSE
                     SLON=DELPOS(NPOS)
                     IF ((((-1.)*SLON) .LE. IFIR) .OR.
     1                  (((-1.)*SLON) .GE. ISEC)) THEN
                        GOTO 800
                     END IF
                END IF
C
                  CALL DETELL (NE1,NS1,SLON)
C
                  CALL DETELL (NE2,NS2,SLON)
C
C  TRANSFER THE MINIMUM ELLIPSE INFORMATION FROM THE ARRAYS OF THE OUTER
C          BLOCK TO THE ARRAYS OF THE INNER BLOCK
C
                  BCLON(1)=ADBLON(NS1,NE1)*RADIAN
                  BCLAT(1)=ADBLAT(NS1,NE1)*RADIAN
                  AXR(1)=AAXR(NS1,NE1)
                  ORIENT(1)=AORENT(NS1,NE1)*RADIAN
                  AXMAJ(1)=AAXMAJ(NS1,NE1)*RADIAN
C
                  BCLON(2)=ADBLON(NS2,NE2)*RADIAN
                  BCLAT(2)=ADBLAT(NS2,NE2)*RADIAN
                  AXR(2)=AAXR(NS2,NE2)
                  ORIENT(2)=AORENT(NS2,NE2)*RADIAN
                  AXMAJ(2)=AAXMAJ(NS2,NE2)*RADIAN
C
C  CALL A SUBROUTINE WHICH CALCULATES THE REQUIRED SEPARATION FOR
C  THE TWO SATELLITES AT THE GIVEN ORBITAL LOCATION.
C
              CALL SEPAR(DELS)
              WRITE(6,100)NAMESA(1),NAMESA(2),SLON,DELS
 100          FORMAT(2X,A8,2X,A8,5X,F8.2,5X,F7.2)
C
```

```
          IF (DELS .GE. DELM(NS1,NS2)) THEN
             DELM(NS1,NS2)=DELS
          END IF
C
          IF (OPTION .EQ. 2) THEN
              DELP(NPOS,NS1,NS2) = DELS
          END IF
C
 800          CONTINUE
 900      CONTINUE
 1000 CONTINUE
C
      CALL WRDM
      IF (OPTION .EQ. 2) THEN
         CALL WRPH
      END IF
C
      END
C
      SUBROUTINE NOINT(NS1,NS2,W1,E1,W2,E2)
C
C     THIS ROUTINE HANDLES THE CASE WHERE THERE IS NO INTERSECTION
C     OF THE FEASIBLE ARCS OF TWO ADMINISTRATIONS.
C     A REQUIRED SEPARATION VALUE IS CALCULATED AT THE MIDPOINT
C     OF THE GAP BETWEEN THE TWO ARCS
C
C     ***************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                       ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
```

```
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C *************************************************************
C
      IF (W2 .LE. W1) THEN
C  ARC OF ADMINISTRATION 2 LIES TO THE WEST OF THE ARC OF ADMINISTRATION 1
           DIFF = ABS(E2-W1)
           NE2 = NELLOC(NS2)
           NE1 = 1
           SLON=0.5*(E2+W1)
      ELSE
C  ARC OF ADMINISTRATION 1 LIES TO THE WEST OF THE ARC OF ADMINISTRATION 2
           NE2 = 1
           NE1 = NELLOC(NS1)
           DIFF = ABS(E1-W2)
           SLON=0.5*(E1+W2)
      END IF
C
C   IF THE TWO ARCS ARE SEPARATED BY MORE THAN 7 DEGREES THEN SUPRESS
C   CALCULATION. INTERFERENCE WILL BE NEGLIGIBLE
C
      IF (DIFF .GT. 5.0) THEN
            DELS = 0.0
            GOTO 5
      END IF
C
C   OTHERWISE, LOCATE SATELLITES AT MIDPOINT OF GAP BETWEEN THEIR ARCS
C   AND CALCULATE DELTA-S
C
                  BCLON(1)=ADBLON(NS1,NE1)*RADIAN
                  BCLAT(1)=ADBLAT(NS1,NE1)*RADIAN
                  AXR(1)=AAXR(NS1,NE1)
                  ORIENT(1)=AORENT(NS1,NE1)*RADIAN
                  AXMAJ(1)=AAXMAJ(NS1,NE1)*RADIAN
C
                  BCLON(2)=ADBLON(NS2,NE2)*RADIAN
                  BCLAT(2)=ADBLAT(NS2,NE2)*RADIAN
                  AXR(2)=AAXR(NS2,NE2)
                  ORIENT(2)=AORENT(NS2,NE2)*RADIAN
                  AXMAJ(2)=AAXMAJ(NS2,NE2)*RADIAN
      DELS=DIFF
      CALL SEPAR(DELS)
C
C SET DELTA-S VALUE EQUAL TO THE REQUIRED SEPARATION IN THE
C                 MIDDLE OF THE GAP
C
  5   DELM(NS1,NS2)=DELS
C
      WRITE(6,100)NAMESA(1),NAMESA(2),SLON,DELS
 100  FORMAT(2X,A8,2X,A8,5X,F8.2,5X,F7.2)
C
C IF THE DELTA-PHI OPTION IS IN EFFECT, THEN SET EVERY VALUE EQUAL
C TO THE SEPARATION REQUIRED IN THE CENTER OF THE GAP
C
      IF (OPTION .EQ. 2) THEN
         DO 10 N=1,IPOS
             DELP(N,NS1,NS2)=DELS
```

```
10        CONTINUE
       END IF
C
       RETURN
       END
C
       SUBROUTINE DETELL(NE,NS,SATLOC)
C
C      THIS SUBROUTINE SELECTS THE APPROPRIATE ELLIPSE FOR THE PRESENT
C      ORBITAL LOCATION. THIS IS DONE BY FINDING THE ELLIPSE IN THE
C      ADMINISTRATION'S INPUT FILE WHICH WAS CALCULATED AT THE CLOSEST
C      ORBITAL LOCATION TO THE PRESENT LOCATION, SATLOC
C
C      ***************************************************************
C
       IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
       CHARACTER*8 NAMESA,SANAME
C
       INTEGER APTNER,APTNET,APTNST,APTNSR
C
       COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                 PFD,ALOGE,ALN10,COIMIN
C
       COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
       COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                 XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
       COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                 UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                 IPTNET(2),IPTNST(2),IPTNSR(2)
C
       COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                 REFLAT(2),REFLON(2),AXR(2),
     2                         ORIENT(2),AXMAJ(2)
C
       COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                 DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
       COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                 ALPHA(2,20),ALPHA0(2,20)
C
       COMMON /DIA/    DT(2),DR(2)
C
       COMMON /LOC/    SLON
C
       COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                 YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
       COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
       COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
       COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1             DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
       COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1               ADT(100),ADR(100)
C
C ***************************************************************
C IF THE SATELLITE'S LOCATION IS EAST OF THE EASTERNMOST LOCATION FOR
```

```
C WHICH ELLIPSES WERE CALCULATED THEN CHOSE THE EASTERNMOST ELLIPSE
C
      IF (SATLOC .GE. EELLOC(NS)) THEN
                NE=NELLOC(NS)
      ELSE
C
C IF THE SATELLITE'S LOCATION IS WEST OF THE WESTERNMOST LOCATION FOR
C WHICH ELLIPSES WERE CALCULATED THEN CHOSE THE WESTERNMOST ELLIPSE
C
          IF (SATLOC .LE. WELLOC(NS)) THEN
              NE=1
          ELSE
                DIFFMN=1.0E+11
                NE=0
                J=NELLOC(NS)
C
C THIS LOOP CHECKS ABSOLUTE DISTANCE BETWEEN SATELLITE LOCATION AND THE
C LOCATIONS OF ALL POSSIBLE ELLIPSES AND TAKES THE SMALLEST
C
                DO 35   N=1,J
                   DIFF=ABS(SATLOC-AELLOC(NS,N))
                   IF (DIFF .LT. DIFFMN) THEN
                     DIFFMN=DIFF
                     NE=N
                   END IF
  35            CONTINUE
          END IF
      END IF
C
      RETURN
      END
C
      SUBROUTINE INDATA
C
C  THIS IS A SUBROUTINE WHICH INPUTS PARAMETERS DESCRIBING THE SERVICE
C  AREAS, THE SATELLITE AND GROUND STATION ANTENNAS, THE FEASIBLE
C  ORBITAL ARCS AND THE ELLIPSE DATA.
C
C     ***************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
```

```
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C ***********************************************************
C
C     ENTER GLOBAL CONSTANTS TO BE USED THROUGHOUT THE PROGRAM
C
      READ(5,*) OPTION
C
      READ(5,*) NUMSAR,COIMIN,INTSP,UFREQ,DFREQ
C 100  FORMAT (I5,F5.1,I5,F6.2,F6.2)
C
C     THE FOLLOWING CONVENTION IS USED WHEN THREE OR MORE ADMINISTRATIONS
C     HAVE IDENTICAL SERVICE AREAS (for example---25 satellites serving U.S.)
C
C     THE SAME SERVICE AREA DATA IS ENTERED UNDER TWO CONSECUTIVE
C     ADMINISTRATIONS. FOR THE FIRST ADMINISTRATION, THE INTEGER VARIABLE
C     NUMSAT IS SET EQUAL TO THE TOTAL NUMBER OF ADMINISTRATIONS (SATELLITES)
C     WITH THE SAME SERVICE AREA (25 in the U.S. example above). FOR THE
C     SECOND ADMINISTRATION, NUMSAT IS SET EQUAL TO 1. THIS IS DONE TO
C     AVOID REDUNDANT CALCULATIONS ON MULTIPLE ADMINISTRATIONS WITH THE
C     SAME SERVICE AREA.
C
      DO 10   NS=1,NUMSAR
C
        READ(5,101) SANAME(NS),NUMSAT(NS)
 101    FORMAT (A8,2X,I5)
C
C      THIS IS THE ANTENNA INFORMATION
C
        READ(5,102) APTNER(NS),APTNET(NS),APTNST(NS),APTNSR(NS),
     !              ADT(NS),ADR(NS)
 102    FORMAT(I2,I2,I2,I2,F5.2,F5.2)
C
        READ(5,103) INTP(NS)
 103    FORMAT(I5)
C
        K=INTP(NS)
C
C      THESE ARE THE TEST POINTS WHICH DEFINE THE SERVICE AREAS.
C
        DO 20         N1 = 1,K
           READ(5,104) ADELAT(NS,N1),ADELON(NS,N1)
 104       FORMAT(F6.2,2X,F7.2)
C
  20    CONTINUE
```

Program DELTA (cont.)

```
C
C      THIS PORTION ENTERS THE MINIMUM ELLIPSE DATA
C
        READ(5,105) NELLOC(NS)
 105    FORMAT (I5)
C
        READ(5,*) WELLOC(NS),EELLOC(NS)
C 106    FORMAT (F6.1,2X,F6.1)
C
           N=NELLOC(NS)
           DO 30  NE=1,N
              READ(5,107)AELLOC(NS,NE),ADBLAT(NS,NE),
     1                   ADBLON(NS,NE),AORENT(NS,NE),AAXMAJ(NS,NE),
     1                   AAXMIN
 107          FORMAT (F6.1,1X,F7.2,1X,F7.2,1X,F7.2,2X,F5.2,2X,F6.2)
C
              AAXMAJ(NS,NE)=AMAX1(AAXMAJ(NS,NE),0.6)
              AAXMIN=AMAX1(AAXMIN,0.6)
              AAXR(NS,NE)=AAXMAJ(NS,NE)/AAXMIN
  30       CONTINUE
C
  10  CONTINUE
C
      RETURN
      END
C
      SUBROUTINE SEPAR(DELS)
C
C      THIS ROUTINE ITERATES TO FIND THE MINIMUM REQUIRED SEPARATION
C      AT A SPECIFIED POINT IN THE GSO FOR THE SATELLITES SERVING TWO
C      ADMINISTRATIONS. THIS IS THE MAIN ROUTINE FOR THE INNER BLOCK OF
C      THE COMPLETE PROGRAM.
C     ***********************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      LOGICAL HIGH
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
```

```
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
      COMMON /WDISCR/ WUDIS(2)
C
      COMMON /CTOI/ COID(2),COIU(2)
C
      DIMENSION LUWTP(2),JDWTP(2)
C
C ***********************************************************
C
C >>>>>>>>>>VARIABLE LIST FOR THIS SUBROUTINE AND INNER BLOCK<<<<<<<<
C
C       DSLON     SATELLITE LOCATIONS IN DEGREES FOR ADMINISTRATIONS
C                 1 AND 2
C
C       RSLON     SATELLITE LOCATIONS IN RADIANS
C
C       GAINS     GAIN OF SATELLITE ANTENNA
C
C       RGAIN     RECEIVING GAIN OF EARTH STATION ANTENNA
C
C       TGAIN     TRANSMITTING GAIN OF EARTH STATION ANTENNA
C
C       UCPHI0    UPLINK HALF POWER BEAMWIDTH FOR EARTH STATION ANTENNA
C
C       DCPHI0    DOWNLINK HALF POWER BEAMWIDTH FOR EARTH STATION ANTENNA
C
C       EIRP      DOWNLINK EIRP FOR SATELLITE TRANSMITTERS
C
C>>>>>>>>>>>>>>>>>>>>>>>>>>>>>ANGLES<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
C
C       PHI(K,J)  ANGLE SEEN AT SATELLITE K BETWEEN AXIS OF SATELLITE
C                 K'S ANTENNA AND TEST POINT J OF SERVICE AREA K
C
C       PHI0(K,J) ELLIPTICAL HALF POWER BEAMWIDTH MEASURED FOR SATELLITE K
C                 TO TEST POINT J IN SERVICE AREA K
C
C       THETA(K,J) TOPOCENTRIC ANGLE BETWEEN TWO SATELLITES AS SEEN FROM
C                  TEST POINT J OF SERVICE AREA K
C
C       ALPHA(K,J)  ANGLE SEEN AT SATELLITE I BETWEEN AXIS OF SATELLITE
C                   I'S ANTENNA AND TEST POINT J OF THE OTHER SERVICE AREA
C
C       PHI0(K,J) ELLIPTICAL HALF POWER BEAMWIDTH MEASURED FOR SATELLITE I
C                 TO TEST POINT J IN THE OTHER SERVICE AREA
C
C>>>>>>>>>>>>>>>>>>>>>>>>>>>>>COORDINATES<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
C
C       XE        RECTANGULAR COORDINATES OF EARTH STATIONS
```

```
C       YE          Z-AXIS IS EARTH POLAR AXIS, +Z TO NORTH
C       ZE          X-Y PLANE IS EQUATORIAL PLANE, +X-AXIS
C                   PASSES THROUGH GREENWICH MERIDIAN
C
C       XO         RECTANGULAR COORDINATES OF SATELLITE LOCATION
C       YO                 FOR GSO Z=0
C
C       REFLAT     LATITUDE AND LONGITUDE OF POINT ON MAJOR AXIS OF THE
C       REFLON     MINIMUM ELLIPSE ON THE EARTH'S SURFACE. CALLED
C                  REFERENCE POINT IN SOUP
C
C>>>>>>>>>>>>>>>>>>>>>>>>>>>>VECTORS<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
C
C       XOAC       ELEMENTS OF VECTOR FROM SATELLITE TO AIMPOINT
C       YOAC                       ON EARTH
C       ZOAC
C
C       XOAKKJ     ELEMENTS OF VECTOR FROM DESIRED SATELLITE TO
C       YOAKKJ     EARTH STATION J OF ITS SERVICE AREA
C       ZOAKKJ
C
C       XOAIKJ     ELEMENTS OF VECTOR FROM INTERFERING SATELLITE
C       YOAIKJ     TO TEST POINT J OF THE OTHER SERVICE AREA
C       ZOAIKJ
C
C       ROAC       RANGE FROM SATELLITE TO ITS AIMPOINT
C
C>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>><<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
C
C            INITIALIZE PARAMETERS
C
      CALL SETUP(DELS)
      CALL VECCAL
C
      DO 10 I=1,2
C
C     ESTIMATE SATELLITE RECEIVING/TRANSMITTING GAIN AND
C     FIND THE REFERENCE POINT LATITUDE AND LONGITUDE
C
         CALL REFCAL(I)
         GAINS(I) = 10.*ALOG10(EAP*AXR(I)*(PI*223./180./AXMAJ(I))**2)
C
C   ESTIMATE THE TRANSMITTING/RECEIVING GAINS AND HALF POWER
C   BEAMWIDTHS FOR THE EARTH STATION ANTENNAS USING THE EQUATIONS
C   FROM SOUP-3
C
       DLAMDA = 3.0E+08/(DFREQ*1.0E+09)
       ULAMDA = 3.0E+08/(UFREQ*1.0E+09)
C
       X0 = DR(I)/DLAMDA
       X1 = DT(I)/ULAMDA
       X2 = 223./180.
C
       RGAIN(I) = 10.*ALOG10(PI*PI*EAP*X0*X0)
C
       TGAIN(I) = 10.*ALOG10(PI*PI*EAP*X1*X1)
C
       UCPHI0(I) = X2/X1
C
       DCPHI0(I) = X2/X0
C
C*** CALCULATE THE DOWNLINK EIRP FOR EACH SATELLITE. THE POWER
C    FLUX DENSITY AT THE AIMPOINT OF EACH ADMINISTRATION IS ASSUMED
C    TO BE EQUAL TO THE CONSTANT PFD.
C
       EIRP(I)=PFD+10.*ALOG10(4*PI*ROAC(I)*ROAC(I)*ER*ER)
```

```
C
  10  CONTINUE
C
C***  >>  OUTER LOOP (OVER K) FOR BOTH SERVICE AREAS  <<
C
      DO 1000  K = 1,2
C
         I = 3-K
C
         JNTP = NTPSA(K)
         WUDIS(K)=10.0
C
C     >>    MIDDLE LOOP (OVER J) FOR ALL TEST POINTS IN AREA K     <<
C     >>CALCULATIONS FIND THE NECESSARY ANGLES FOR ALL TEST POINTS <<
C
         DO 900  J = 1,JNTP
C
            CALL XPHI (K,K,J,PH)
            PHI(K,J)=PH
            CALL XPHI0 (K,K,J,PO)
            PHI0(K,J)=PO
C
C     THIS STEP FINDS THE TEST POINT IN ADMINISTRATION K WHICH IS CLOSEST
C     TO THE -3 DB CONTOUR OF ADMINISTRATION K'S SATELLITE RECEIVING ANTENNA.
C     THIS TEST POINT IS USED AS THE SOURCE OF ALL DESIRED UPLINK TRANSMISSIONS
C     FROM K AS IT REPRESENTS THE WORST CASE. THE RECEIVING DISCRIMINATION FROM
C     K'S SATELLITE TO A TRANSMISSION FROM THIS POINT IS SAVED.
C
               GO TO(11,12,13,14,15)IPTNSR(K)
C
 11            CALL PTNST1(PH,PO,GAINS(K),RDISC)
               GOTO 16
C
 12            CALL PTNST2(PH,PO,GAINS(K),RDISC)
               GOTO 16
C
 13            CALL PTNST3(PH,PO,GAINS(K),RDISC)
               GOTO 16
C
 14            CALL PTNST4(PH,PO,GAINS(K),RDISC)
               GOTO 16
C
 15            CALL PTNST5(PH,PO,GAINS(K),RDISC)
C
 16            IF (RDISC .LT. WUDIS(K)) THEN
                     WUDIS(K)=RDISC
               END IF
C
            CALL XPHI0 (I,K,J,AO)
            ALPHA0(I,J)=AO
            CALL XPHI (I,K,J,AL)
            ALPHA(I,J)=AL
            CALL ZPHI (I,K,J,TH)
            THETA(K,J)=TH
C
 900     CONTINUE
C
 1000 CONTINUE
C
      DO 800         K = 1,2
C
         I = 3-K
C
         JNTP=NTPSA(K)
C
         NTPI=NTPSA(I)
```

```
C
        COID(K)=200.
C
        DO 700      J = 1,JNTP
C
C     FIND THE DOWNLINK C/I RATIO USING CALCULATIONS BASED ON SOUP.
C
           CALL DOWNLK(I,K,J,COI)
C
C      COMPARE THE DOWNLINK C/I AT THIS TEST POINT WITH THE WORST VALUE.
C      IF IT IS LOWER THEN USE IT AS THE WORST VALUE AND SAVE THE INDEX
C      OF THE TEST POINT.
C
           IF (COI .LT. COID(K)) THEN
                 COID(K) = COI
                 JDWTP(K) = J
           END IF
 700    CONTINUE
C
        COIU(K)=200.
C
C     FIND THE UPLINK C/I RATIO FOR AN INTERFERING TRANSMITTER AT
C     TEST POINT L OF ADMINISTRATION I FOR ALL POSSIBLE L'S
C
         DO 500  L = 1,NTPI
C
C     THIS CALLS A SUBROUTINE THAT CALCULATES THE UPLINK C/I RATIO
C
           CALL UPLK(I,K,L,COI)
C
              IF (COI .LT. COIU(K)) THEN
                 COIU(K)=COI
                 LUWTP(K)=L
              END IF
C
 500     CONTINUE
C
 600    CONTINUE
C
 800  CONTINUE
      ICOUNT=1
C
C    THIS PORTION CALLS A SUBROUTINE THAT FINDS THE WORST TOTAL LINK
C    C/I BY ASSUMING THAT THE C/I RATIO AT THE OUTPUT OF THE
C    SATELLITE IS THE SAME AS AT THE INPUT
C
      CALL COILK(WCOIL)
C
C    THIS PORTION USES A BINARY SEARCH TO FIND A SUITABLE SPACING
C
C    IF THE LINK C/I IS SIGNIFICANTLY LESS THAN THE PERMISSIBLE
C    LINK C/I RATIO THEN THE SATELLITES NEED TO BE SPACED FURTHER
C    THAN THEY ARE CURRENTLY
C
C    IF THE LINK C/I IS SIGNIFICANTLY LARGER THAN THE PERMISSIBLE
C    LINK C/I RATIO THEN THE SATELLITES CAN BE SPACED LESS
C    THAN THEY ARE CURRENTLY
C
C    IF THE LINK C/I IS ACCEPTABLE THEN STOP THE SEARCH
C
      DELCOI = COIMIN-WCOIL
      IF (ABS(DELCOI) .LT. (.001*COIMIN)) THEN
         RETURN
      ELSE
         IF (DELCOI .LT. 0.0) THEN
C
```

```
C  THE LINK C/I RATIO IS HIGHER THAN IT NEEDS TO BE
C  IF THE SATELLITES ARE NOW COLLOCATED, THEN THE REQUIRED SEPARATION
C  IS ZERO. IF NOT THEN THEY NEED TO BE SPACED FARTHER APART. IF
C  THE LINK C/I RATIO IS MORE THAN 1 dB TOO HIGH, THEN THEY ARE SPACED
C  BY AN ADDITIONAL 1 DEGREE. IF IT IS LESS THAN 1 DB TOO HIGH THEN THEY
C  ARE SPACED BY AN ADDITIONAL 0.1 DEGREE
C
                IF (DELS .EQ. 0.0) THEN
                   RETURN
                END IF
                HIGH = .TRUE.
                IF (DELCOI .LT. -1.0) THEN
                   STEP = -1.0
                ELSE
                   STEP = -0.1
                END IF
             ELSE
C
C  THE LINK C/I RATIO IS LOWER THAN IT NEEDS TO BE.
C  THE SATELLITES NEED TO BE SPACED LESS FAR APART. IF THE
C  THE LINK C/I RATIO IS MORE THAN 1 dB TOO LOW, THEN THEY ARE MOVED
C  CLOSER BY AN ADDITIONAL 1 DEGREE. IF IT IS LESS THAN 1 DB TOO LOW THEN
C  THEY ARE MOVED CLOSER BY AN ADDITIONAL 0.1 DEGREE
C
                HIGH = .FALSE.
                IF (DELCOI .GT. 1.0) THEN
                   STEP = 1.0
                ELSE
                   STEP = 0.1
                END IF
             END IF
          END IF
C
 2500     DELS = DELS + STEP
          DELS = AMAX1(DELS,0.0)
          ICOUNT = ICOUNT + 1
C
C  THIS SEQUENCE WAS ADDED SO THAT IN EXPERIMENTATION THE PROGRAM
C  DOES NOT WIND UP IN INFINITE LOOPS
C
          IF (ICOUNT .EQ. 20) THEN
            WRITE(6,999)
 999        FORMAT(2X,'TOO MANY ITERATIONS')
            STOP
          END IF
C
          IF (DSLON(1) .LT. DSLON(2)) THEN
             DSLON(1)=SLON-DELS/2.0
             DSLON(2)=SLON+DELS/2.0
          ELSE
             DSLON(1)=SLON+DELS/2.0
             DSLON(2)=SLON-DELS/2.0
          END IF
C
          RSLON(1)=DSLON(1)*RADIAN
          RSLON(2)=DSLON(2)*RADIAN
C
C         RECALCULATE RANGE FOR NEW SPACING
C
          CALL VECCAL
          DO 2800        K = 1,2
C
             I = 3-K
C
             J=JDWTP(K)
             CALL ZPHI (I,K,J,TH)
```

```
           THETA(K,J)=TH
C
C      RECALCUTE WORST DOWNLINK POINT
C
             CALL DOWNLK(I,K,J,COI)
C
           COID(K)=COI
C
           L=LUWTP(K)
           CALL ZPHI (K,I,L,TH)
           THETA(I,L)=TH
C
C     RECALCULATE WORST UPLINK POINT
C
           CALL UPLK(I,K,L,COI)
C
           COIU(K)=COI
C
 2800 CONTINUE
        CALL COILK(WCOIL)
C
C   THE SATELLITES ARE SPACED FARTHER APART OR PUSHED CLOSER TOGETHER
C   UNTIL A POINT IS REACHED WHERE THE SIGN OF DELCOI SWITCHES FROM + TO -
C   OR FROM - TO +. WHEN THIS OCCURS ONE HAS A LOWER BOUND ON THE MINIMUM
C   REQUIRED SATELLITE SEPARATION, SMALL, AND AN UPPER BOUND, BIG
C
        DELCOI = COIMIN - WCOIL
        IF (ABS(DELCOI) .LT. (.001*COIMIN)) THEN
          RETURN
        ELSE
          IF ((DELCOI .LT. 0.0) .AND. (DELS .LE. 0.0)) THEN
             RETURN
          END IF
          IF ((DELCOI .LT. 0.0) .AND. (HIGH .EQV. .FALSE.)) THEN
             BIG=DELS
             SMALL=DELS-STEP
          ELSE
           IF ((DELCOI .GT. 0.0) .AND. HIGH) THEN
             SMALL=DELS
             BIG=DELS-STEP
           ELSE
             GOTO 2500
           END IF
          END IF
        END IF
C
C SET GUESS TO AVERAGE OF UPPER BOUND AND LOWER BOUND
C
 3700 AVG=(BIG+SMALL)/2.0
        DELS=AMAX1(0.0,AVG)
C
C       REPEAT THE C/I CALCULATIONS ONCE MORE WITH THE SATELLITES SPACED
C       BY THE DISTANCE AVG. AFTERWARDS RE-SET THE UPPER AND LOWER BOUNDS
C
        IF (DSLON(1) .LT. DSLON(2)) THEN
           DSLON(1)=SLON-DELS/2.0
           DSLON(2)=SLON+DELS/2.0
        ELSE
           DSLON(1)=SLON+DELS/2.0
           DSLON(2)=SLON-DELS/2.0
        END IF
C
        RSLON(1)=DSLON(1)*RADIAN
        RSLON(2)=DSLON(2)*RADIAN
C
        CALL VECCAL
```

```
      DO 3800          K = 1,2
C
         I = 3-K
C
         J=JDWTP(K)
         CALL ZPHI (I,K,J,TH)
         THETA(K,J)=TH
C
           CALL DOWNLK(I,K,J,COI)
C
         COID(K)=COI
C
         L=LUWTP(K)
         CALL ZPHI (K,I,L,TH)
         THETA(I,L)=TH
C
         CALL UPLK(I,K,L,COI)
C
C
         COIU(K)=COI
C
 3800 CONTINUE
C
      CALL COILK(WCOIL)
C
      DELCOI = COIMIN - WCOIL
      IF (ABS(DELCOI) .LT. (.001*COIMIN)) THEN
C
C ACCEPT THIS VALUE AS THE VALUE OF DELTA-PHI
C
         RETURN
      END IF
C
      IF (DELCOI .LT. 0.0) THEN
C
C SATELLITES ARE TOO FAR APART. RE-SET UPPER BOUND TO CURRENT SEPARATION
C
         BIG=DELS
      ELSE
         SMALL=DELS
C
C SATELLITES ARE TOO CLOSE. RE-SET LOWER BOUND TO CURRENT SEPARATION
C
      END IF
C
C  THIS IS ANOTHER CHECK ON THE NUMBER OF ITERATIONS TO PREVENT
C  EXCESSIVE RUN TIMES DURING EXPERIMENTATION
C
      ICOUNT=ICOUNT+1
      IF (ICOUNT .EQ. 20) THEN
         WRITE(6,999)
         STOP
      END IF
      GOTO 3700
C
      END
C
      SUBROUTINE XPHI0 (I,K,J,P0)
C
C     >> THIS ROUTINE COMPUTES THE ELLIPTICAL BEAM HALF POWER
C     >> BEAM WIDTH IN A PLANE ORTHOGONAL TO THE ANTENNA AXIS USING
C     >> THE METHOD GIVEN IN THE SOUP-3 MANUAL
C     >> ON PAGES III-10 TO III-13.  A MORE DETAIL EXPLAINATION OF
C     >> A SIMILAR PROCEDURE IS FOUND IN THE SOUP-5 MANUAL
C     >> ON PAGES 3-3 TO 3-10
C     ******************************************************************
```

```
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C ************************************************************
C
C IN THIS SECTION THE COMPONENTS OF THE UNIT VECTORS DEFINING A NEW
C COORDINATE SYSTEM IN THE PLANE ORTHOGONAL TO THE ANTENNA AXIS ARE
C CALCULATED
C
      SINPHS = SIN(RSLON(I))
      COSPHS = COS(RSLON(I))
C
      COSW = COS(BCLAT(I)) * COS(RSLON(I)-BCLON(I))
      SINW = SIN(ACOS(COSW))
C
      RSLAT = 0.
      IF ( BCLON(I) .EQ. RSLON(I) ) GO TO 1
      IF ( BCLAT(I) .EQ. 0.0) GO TO 2
      ARG = COS(BCLAT(I)) * SIN(ABS(BCLON(I)-RSLON(I))) / SINW
```

```
      A = ASIN(ARG)
      IF (BCLON(I).GT.RSLON(I) .AND. BCLAT(I).GT. 0.0) A=2.*PI-A
      IF (BCLON(I).LT.RSLON(I) .AND. BCLAT(I).LT. 0.0) A=PI-A
      IF (BCLON(I).GT.RSLON(I) .AND. BCLAT(I).LT. 0.0) A=PI+A
C
      COSA = COS(A)
      SINA = SIN(A)
      GO TO 3
C
C  THIS SECTION IS USED ONLY WHEN THE SATELLITE IS DIRECTLY OVERHEAD
C  THAT IS THE SATELLITE LONGITUDE IS THE SAME AS THE AIMPOINT LONGITUDE
C
 1    CONTINUE
      COSA = -1.
      SINA = 0.
      A = PI
      IF (BCLAT(I) .LT. 0.0) GO TO 3
      COSA = 1.
      A = 0.
      GO TO 3
C
C   THIS SECTION IS USED ONLY WHEN THE AIMPOINT OF THE SERVICE AREA IS ON
C   THE EQUATOR
C
 2    CONTINUE
      COSA = 0.
      SINA = 1.
      A = PI/2.
      IF (BCLON(I) .LT. RSLON(I)) GO TO 3
      SINA = -1.
      A = 1.5*PI
C
 3    CONTINUE
      TANT = SINW / (GCR - COSW)
      TRAD = ATAN(TANT)
      SINT = SIN(TRAD)
      COST = COS(TRAD)
C
      A21 = - COSA * SINPHS
      A22 =   COSA * COSPHS
      A23 =   SINA
C
      A31 = SINT * COSPHS + COST * SINA * SINPHS
      A32 = SINT * SINPHS - COST * SINA * COSPHS
      A33 = COST * COSA
C
      CSFLAT = COS(REFLAT(I))
C
C THIS CALCULATES COMPONENTS OF A VECTOR FROM THE ORIGIN TO THE REFERENCE
C POINT ON THE MAJOR AXIS OF THE ELLIPSE ON THE EARTH'S SURFACE
C
      VR1 = CSFLAT * COS(REFLON(I))
      VR2 = CSFLAT * SIN(REFLON(I))
      VR3 = SIN(REFLAT(I))
C
C THIS CALCULATES THE COMPONENTS OF A VECTOR FROM THE ORIGIN TO THE
C INTERSECTION OF THE SATELLITE'S ANTENNA AXIS WITH THE EARTH
C
      CSBLAT = COS(BCLAT(I))
      VC1 = CSBLAT * COS(BCLON(I))
      VC2 = CSBLAT * SIN(BCLON(I))
      VC3 = SIN(BCLAT(I))
C
C THIS CALCULATES THE COMPONENTS OF A VECTOR FROM THE ORIGIN TO EARTH
C STATION OF INTEREST
C
```

```
      COSTE = COS(RELAT(K,J))
      VE1 = COSTE * COS(RELON(K,J))
      VE2 = COSTE * SIN(RELON(K,J))
      VE3 = SIN(RELAT(K,J))
C
C CALCULTES COMPONENTS OF VECTOR FROM ORIGIN TO SATELLITE
C
      VS1 = GCR * COS(RSLON(I))
      VS2 = GCR * SIN(RSLON(I))
      VS3 = 0.0
C
      VRMVC1 = VR1 - VC1
      VRMVC2 = VR2 - VC2
      VRMVC3 = VR3 - VC3
C
      VEMVS1 = VE1 - VS1
      VEMVS2 = VE2 - VS2
      VEMVS3 = VE3
C
C  TWO ANGLES, S1 AND S2 ARE CALCULATED HERE. S2 IS THE ANGLE BETWEEN THE
C  VECTOR JOINING THE AIMPOINT OF THE SATELLITE ANTENNA AND THE EARTH TEST
C  POINT IN QUESTION AND THE VECTOR A2 CALCULATED EARLIER.
C  S1 IS THE ANGLE BETWEEN THE MAJOR AXIS OF THE
C  MINIMUM ELLIPSE COVERING THE SERVICE AREA AND A2.
C
      S1NUMR = A31*VRMVC1 + A32*VRMVC2 + A33*VRMVC3
      S1DENR = A21*VRMVC1 + A22*VRMVC2 + A23*VRMVC3
C
      S2NUMR = A31*VEMVS1 + A32*VEMVS2 + A33*VEMVS3
      S2DENR = A21*VEMVS1 + A22*VEMVS2 + A23*VEMVS3
C
      IF (S1DENR. NE .0.0)  GO TO 10
      S1 = PI / 2.0
      GO TO 15
   10 S1 = ATAN(S1NUMR/S1DENR)
C
   15 IF (S2DENR. NE .0.0)  GO TO 20
      S2 = PI / 2.0
      GO TO 25
   20 S2 = ATAN(S2NUMR/S2DENR)
C
C SIGMA IS THE ANGLE BETWEEN THE VECTOR FROM THE AIMPOINT TO THE
C TESTPOINT IN QUESTION AND THE MAJOR AXIS OF THE ELLIPSE
C
   25 SIGMA = S2 - S1
      CS = COS(SIGMA)
      SS = SIN(SIGMA)
      AR = AXR(I)
      P0 = AXMAJ(I) / SQRT(CS*CS + AR*AR * SS*SS)
C
      RETURN
      END
C
      SUBROUTINE ICONST
C
C THIS SUBROUTINE ENTERS VARIOUS CONSTANTS USED THROUGHOUT THE
C OTHER ROUTINES OF THIS PROGRAM
C
C***********************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
C***********************************************************************
```

```
C
      E = 2.7182818285
      PI = 3.1415926536
      RADIAN = PI / 180.0
      DEGREE = 180.0 / PI
      GCR = 6.6134
C
C GCR = RADIUS OF GEO-STATIONARY ORBIT IN EARTH RADII
C
      ER = 6.371E+06
C
C ER = RADIUS OF EARTH IN METERS
C
      ALOGE = 0.4342944819
      ALN10 = 2.3025850930
      ERDB = -20.0 * ALOG10(ER)
      PFD = -90.
C
C CONSTANT PFD (POWER FLUX DENSITY) AT AIMPOINTS FOR ALL ADMINISTRATIONS
C ON THE DOWNLINK
C
      EAP = 0.6
C
C     EAP = APPERTURE EFFICIENCY OF REFLECTOR ANTENNAS
C
      RETURN
      END
C
      SUBROUTINE KPHI (I,K,J,PHITK)
C     ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
```

```
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C ***********************************************************
C
C        FIND THE ANGLE BETWEEN TEST POINT J OF SERVICE AREA K
C     AND THE AIMPOINT OF SATELLITE I AS SEEN FROM SATELLITE I
C
      XOAKKJ = XE(K,J) -  XO(I)
      YOAKKJ = YE(K,J) -  YO(I)
      ZOAKKJ = ZE(K,J)
      ROAKKJ = SQRT(XOAKKJ*XOAKKJ + YOAKKJ*YOAKKJ + ZOAKKJ*ZOAKKJ)
C
      COSPHI = (XOAC(I) * XOAKKJ + YOAC(I) * YOAKKJ + ZOAC(I) * ZOAKKJ)
     $          / (ROAC(I) * ROAKKJ)
      IF (COSPHI .GT. 1.0) THEN
         COSPHI=1.0
      ELSE
         IF (COSPHI .LT. -1.0) THEN
            COSPHI=-1.0
         ELSE
            PHITK = ACOS(COSPHI)
         END IF
      END IF
C
      RETURN
      END
C
      SUBROUTINE ZPHI (I,K,J,ATHETA)
C     **************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
```

```
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C **************************************************************
C
C     THIS ROUTINE CALCULATES THE TOPOCENTRIC ANGLE BETWEEN THE
C     TWO SATELLITES AS SEEN FROM THE EARTH STATION J OF AREA K
C
C***  >>  CALCULATE OFF AXIS VECTOR COMPONENTS (IKJ)  <<
C
      XOAIKJ = XE(K,J) - XO(I)
      YOAIKJ = YE(K,J) - YO(I)
      ZOAIKJ = ZE(K,J)
      ROAIKJ = SQRT(XOAIKJ*XOAIKJ + YOAIKJ*YOAIKJ + ZOAIKJ*ZOAIKJ)
C
      XOAKKJ = XE(K,J) - XO(K)
      YOAKKJ = YE(K,J) - YO(K)
      ZOAKKJ = ZE(K,J)
      ROAKKJ = SQRT(XOAKKJ*XOAKKJ + YOAKKJ*YOAKKJ + ZOAKKJ*ZOAKKJ)
C
      TNUMER = XOAKKJ * XOAIKJ + YOAKKJ * YOAIKJ + ZOAKKJ * ZOAIKJ
      TDENOM = ROAKKJ * ROAIKJ
C
      TEMPU = TNUMER / TDENOM
C
      ATHETA = 0.0
      IF (ABS(TEMPU) .LT. 1.0) ATHETA = ACOS(TEMPU)
C
      RETURN
      END
C
      SUBROUTINE REFCAL(N)
C
C***  >> THIS ROUTINE CALCULATES THE REFERENCE POINT LAT. & LON. <<
C***  >>  BASED ON THE ALGORITHM IN SOUP MANUAL 3.4, MAY 1983    <<
C     *****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
```

```
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C ***********************************************************
C
C     TRANSLATE COORDINATES OF THE AIMPOINT TO PLANE ORTHOGONAL
C     TO ANTENNA AXIS OF DESIRED SATELLITE, CALLED THE ANTENNA
C     PLANE
C
      PGMPS = BCLON(N) - RSLON(N)
      COSTG = COS(BCLAT(N))
      COSPP = COS(PGMPS)
      Q1 = COSTG * SIN(PGMPS)
      Q2 = GCR - COSTG * COSPP
      Q3 = SQRT(Q1**2+Q2**2)
C
      SX = ATAN2(Q1,Q2)
      SY = ATAN2(SIN(BCLAT(N)),Q3)
C
C     FIND X AND Y DISTANCES IN THE ANTENNA PLANE
C     FROM THE BEAM AXIS OF A POINT ON THE ELLIPSE MAJOR
C     AXIS, ONE HALF SEMIMAJOR AXIS FROM THE AIMPOINT
C
      AMAJ2 = AXMAJ(N) * 0.5
      SX2 = AMAJ2 * COS(ORIENT(N))
      SY2 = AMAJ2 * SIN(ORIENT(N))
C
```

```
C     FIND A REFERENCE POINT OF THE ELLIPSE MAJOR AXIS IN THE ANTENNA PLANE
C
      X1 = SX + SX2
      Y1 = SY + SY2
C
      Q4 = ACOS(COS(X1) * COS(Y1))
      Q5 = SIN(Q4)
      T = GCR * Q5
      IF (T .LE. 1.0)  GO TO 10
C
C     IF T > 0 THE REFERENCE POINT MUST BE PLACED ON THE OTHER SIDE
C     OF THE MAJOR AXIS
C
      X1 = SX - SX2
      Y1 = SY - SY2
      Q4 = ACOS(COS(X1) * COS(Y1))
      Q5 = SIN(Q4)
      T = GCR * Q5
      IF (T .LE. 1.0 .AND. T .GE. -1.0)  GO TO 10
      IF (T .GT. 0.)  T = 1.0
      IF (T .LT. 0.)  T = -1.0
C
C     IF T IS STILL > 1, AN ERROR EXISTS, THE ELLIPSE DOES NOT INTERSECT
C                                   THE EARTH
C
      WRITE(6,901) T
 901  FORMAT(/10X,'****** POSSIBLE ERROR IN ELLIPSE SELECTION ',
     $        F5.1)
C
  10  P1 = SIN(Y1)/Q5
      P1 = AMAX1(P1,-1.0)
      P1 = AMIN1(P1,1.0)
      PX = ASIN(P1)
      IF (X1 .LT. 0.0)  PX = PI - PX
      BLAM = ASIN(T) - Q4
      REFLAT(N) = ASIN(SIN(BLAM)*SIN(PX))
      AL = ACOS(COS(BLAM)/COS(REFLAT(N)))
      IF ( ABS(PX) .GT. PI/2.)  AL = -AL
      REFLON(N) = RSLON(N) + AL
C
      RETURN
      END
C
      SUBROUTINE DOWNLK(I,K,J,DCOI)
C     *****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
```

```
     2                        ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C *************************************************************
C
C     THIS IS A SUBROUTINE TO CALCULATE THE DOWNLINK C/I AT
C     TEST POINT J IN THE SERVICE AREA OF K WITH
C     SATELLITE I INTERFERING.
C
      PH=PHI(K,J)
      PO=PHI0(K,J)
      AL=ALPHA(I,J)
      AO=ALPHA0(I,J)
      TH=THETA(K,J)
      GK=GAINS(K)
      GI=GAINS(I)
C
      IF (IPTNST(K) .EQ. 6) THEN
         TDISC = -3.
         GOTO 60
      END IF
C
      GO TO(10,20,30,40,50),IPTNST(K)
C
 10   CALL PTNST1(PH,PO,GK,TDISC)
      GOTO 60
C
 20   CALL PTNST2(PH,PO,GK,TDISC)
      GOTO 60
C
 30   CALL PTNST3(PH,PO,GK,TDISC)
      GOTO 60
C
 40   CALL PTNST4(PH,PO,GK,TDISC)
      GOTO 60
C
 50   CALL PTNST5(PH,PO,GK,TDISC)
C
 60   IF (TDISC .LT. -3.) THEN
         TDISC=-3.
```

```
      END IF
C
C     CALCULATE DISTANCE FROM SATELLITE TRANSMITTER TO EARTH RECEIVER
C
      XOAKJ=XE(K,J)-XO(K)
      YOAKJ=YE(K,J)-YO(K)
      ZOAKJ=ZE(K,J)
      ROAKJ=SQRT(XOAKJ*XOAKJ+YOAKJ*YOAKJ+ZOAKJ*ZOAKJ)
C
C     CALCULATE NUMERATOR OF C/I EQUATION FOR THE DOWNLINK
C
      DESPR=EIRP(K)+RGAIN(K)+TDISC-20.0*ALOG10(ROAKJ*ER)
C
      GO TO(110,120,130,140,150),IPTNST(I)
C
 110  CALL PTNST1(AL,AO,GI,TDISC)
      GOTO 160
C
 120  CALL PTNST2(AL,AO,GI,TDISC)
      GOTO 160
C
 130  CALL PTNST3(AL,AO,GI,TDISC)
      GOTO 160
C
 140  CALL PTNST4(AL,AO,GI,TDISC)
      GOTO 160
C
 150  CALL PTNST5(AL,AO,GI,TDISC)
C
 160  GO TO(210,220,230,240,250),IPTNER(K)
C
 210  CALL PTNER1(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
      GOTO 260
C
 220  CALL PTNER2(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
      GOTO 260
C
 230  CALL PTNER3(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
      GOTO 260
C
 240  CALL PTNER4(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
      GOTO 260
C
 250  CALL PTNER5(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
C
C     CALCULATE DISTANCE FROM INTERFERING SATELLITE TO TEST POINT J
C
 260  XOAIJ=XE(K,J)-XO(I)
      YOAIJ=YE(K,J)-YO(I)
      ZOAIJ=ZE(K,J)
      ROAIJ=SQRT(XOAIJ*XOAIJ+YOAIJ*YOAIJ+ZOAIJ*ZOAIJ)
C
C     FIND DENOMINATOR IN C/I CALCULATION
C
      PWRINT=EIRP(I)+TDISC+RDIR-20.0*ALOG10(ROAIJ*ER)
C
C     CALCULATE DOWNLINK C/I IN DB
C
      DCOI=DESPR-PWRINT
C
      RETURN
      END
C
      SUBROUTINE UPLK(I,K,L,UCOI)
C
C     THIS IS A SUBROUTINE TO CALCULATE THE UPLINK C/I
```

```
C       AT SATELLITE K RECEIVING A TRANSMISION FROM TEST
C       POINT J. INTERFERENCE IS FROM TEST POINT L OF
C       SERVICE AREA I.
C
C       ***********************************************************
C
        IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
        CHARACTER*8 NAMESA,SANAME
C
        INTEGER APTNER,APTNET,APTNST,APTNSR
C
        COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                  PFD,ALOGE,ALN10,COIMIN
C
        COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
        COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                  XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
        COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                  UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                  IPTNET(2),IPTNST(2),IPTNSR(2)
C
        COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                  REFLAT(2),REFLON(2),AXR(2),
     2                         ORIENT(2),AXMAJ(2)
C
        COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                  DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
        COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                  ALPHA(2,20),ALPHA0(2,2C)
C
        COMMON /DIA/    DT(2),DR(2)
C
        COMMON /LOC/    SLON
C
        COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                  YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
        COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
        COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
        COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1             DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
        COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1               ADT(100),ADR(100)
C
        COMMON /WDISCR/ WUDIS(2)
C
C ***********************************************************
C
C       FIND NUMERATOR OF C/I CALCULATION
C
C       THIS TERM IS THE DISCRIMINATION THE SATELLITE GIVES TO THE
C       DESIRED TRANSMISSION FROM THE WORST TEST POINT IN ITS SERVICE
C       AREA. THIS WAS CALCULATED AND SAVED IN THE SUBROUTINE SEPAR
C
        RDISC = WUDIS(K)
```

```
C
C   THIS CHECK WAS PUT IN DURING EXPERIMENTATION. THIS VALUE SHOULD
C   NEVER FALL BELOW -3 DB
C
      IF (RDISC .LT. -3.) THEN
          RDISC=-3.
      END IF
C
      DESPR=RDISC+TGAIN(K)
C
C     FIND DENOMINATOR OF C/I CALCULATION
C
C     FIRST FIND THE RECEIVING DISCRIMINATION PRESENTED TO UNWANTED
C     SIGNAL BY THE SATELLITE ANTENNA
C
      GO TO(11,12,13,14,15)IPTNSR(I)
C
   11 CALL PTNST1(ALPHA(K,L),ALPHA0(K,L),GAINS(K),RDISC)
      GOTO 20
C
   12 CALL PTNST2(ALPHA(K,L),ALPHA0(K,L),GAINS(K),RDISC)
      GOTO 20
C
   13 CALL PTNST3(ALPHA(K,L),ALPHA0(K,L),GAINS(K),RDISC)
      GOTO 20
C
   14 CALL PTNST4(ALPHA(K,L),ALPHA0(K,L),GAINS(K),RDISC)
      GOTO 20
C
   15 CALL PTNST5(ALPHA(K,L),ALPHA0(K,L),GAINS(K),RDISC)
C
   20 GO TO(110,120,130,140,150),IPTNET(K)
C
C  SECOND FIND THE TRANSMITTING DISCRIMINATION FROM THE EARTH STATION
C  ANTENNA IN THE UNWANTED ADMINISTRATION'S SERVICE AREA
C
  110 CALL PTNER1(THETA(I,L),UCPHI0(K),UFREQ,TGAIN(I),TDISC)
      GOTO 160
C
  120 CALL PTNER2(THETA(I,L),UCPHI0(K),UFREQ,TGAIN(I),TDISC)
      GOTO 160
C
  130 CALL PTNER3(THETA(I,L),UCPHI0(K),UFREQ,TGAIN(I),TDISC)
      GOTO 160
C
  140 CALL PTNER4(THETA(I,L),UCPHI0(K),UFREQ,TGAIN(I),TDISC)
      GOTO 160
C
  150 CALL PTNER5(THETA(I,L),UCPHI0(K),UFREQ,TGAIN(I),TDISC)
C
  160 PWRINT=RDISC+TDISC
C
C     CALCULATE UPLINK C/I
C
      UCOI=DESPR-PWRINT
C
      RETURN
      END
C
      SUBROUTINE PTNST1(PT,P0,G,DISC)
C
C     FSS SATELLITE TX PATTERN FROM CCIR REPORT 558-2
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
```

```
     1                 PFD,ALOGE,ALN10,COIMIN
C
      X=PT/P0
      IF (X .LE. 1.3)  GO TO 10
      IF (X .LE. 3.15)  GO TO 20
C
      DISC = -(7.5 + 25.0 * ALOG10(X))
      IF (DISC.LE.(-G-10.)) DISC = -G-10.
      GO TO 40
C
   10 DISC = -12.0 * X * X
      GO TO 40
C
   20 DISC = -20.0
C
   40 RETURN
      END
C
      SUBROUTINE PTNST2(PT,P0,G,DISC)
C
C     FSS SATELLITE TX PATTERN FROM RARC 83 $ 5.1.10.1
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      DP0 =P0*DEGREE
      X1 =PT/P0
      X2 =DP0/0.8
      X3 =.5*(1.-1./X2)
C
      P1 =.4/DP0+X3
      P2 =1.155/DP0 +X3
      P3 =1.60/DP0+X3
      P4 = 4.0/DP0+X3
      P5 = 6.968/DP0 +X3
      P6 = 10.**((G-11.5)/25.)/X2 + X3
C
      IF (X1 .LE. 0.5)  GO TO 10
      IF (X1 .LE. P2)  GO TO 12
      IF (X1 .LE. P3)  GO TO 14
      IF (X1 .LE. P4)  GO TO 16
      IF (X1 .LE. P5)  GO TO 18
      IF (X1 .LE. P6)  GO TO 20
C
      DISC = -G
      GO TO 40
C
 10   DISC = -12.0 * X1 * X1
      GO TO 40
C
 12   DISC = -18.75*DP0*DP0*(X1-X3)*(X1-X3)
      GO TO 40
C
 14   DISC = -25
      GO TO 40
C
 16   DISC = -17.5 - 25.*ALOG10((X1-X3)*X2)
      GO TO 40
C
 18   DISC = -35.
      GO TO 40
C
 20   DISC = -11.5 - 25.* ALOG10((X1-X3)*X2)
C
```

```
 40     RETURN
        END
C
        SUBROUTINE PTNST3(PT,P0,G,DISC)
C
C       FSS SATELLITE TX PATTERN FROM RARC 83 $ 5.1.10.1
C       WITH MODIFICATION
C
        IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
        COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                 PFD,ALOGE,ALN10,COIMIN
        DPO = P0*DEGREE
        X1 = PT/P0
        X2 = DP0/0.8
        X3 = .5*(1.-1./X2)
C
        IF (X1 .LE. 0.5)  GO TO 10
        P2 = 1.265/DP0 +X3
        IF (X1 .LE. P2)  GO TO 12
        P3 = 10.**((30.-24.)/30.)
        IF (X1 .LE. P3)  GO TO 14
        P4 = 10.**((G-24.)/30.)
        IF (X1 .LE. P4)  GO TO 16
C
        DISC = -G
        GO TO 40
C
 10     DISC = -12.0 * X1 * X1
        GO TO 40
C
 12     DISC = -18.75*DP0*DP0*(X1-X3)*(X1-X3)
        GO TO 40
C
 14     DISC = -30.
        GO TO 40
C
 16     DISC = -24.-30.*ALOG10(X1)
C
 40     RETURN
        END
C
        SUBROUTINE PTNST4(PT,P0,G,DISC)
C
C       FSS SATELLITE TX PATTERN FROM RARC 83 $5.10.1
C       WITH MODIFICATION
C
        IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
        COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                 PFD,ALOGE,ALN10,COIMIN
C
        DP0 = P0*DEGREE
        X1 = PT/P0
        X2 = DP0/0.8
        X3 = .5*(1.-1./X2)
C
        IF (X1 .LE. 0.5)  GO TO 10
        P2 = 1.265/DP0 +X3
        IF (X1 .LE. P2)  GO TO 12
        P3 = 10.**((30.-24.)/30.)
        IF (X1 .LE. P3)  GO TO 14
        P4 = 10.**((G-24.)/30.)
        IF (X1 .LE. P4)  GO TO 16
C
        DISC = -G
```

```
      GO TO 40
C
 10   DISC = -12.0 * X1 * X1
      GO TO 40
C
 12   DISC = -18.75*DP0*DP0*(X1-X3)*(X1-X3)
      GO TO 40
C
 14   DISC = -30.
      GO TO 40
C
 16   DISC = -24.-30.*ALOG10(X1)
C
 40   RETURN
      END
C
      SUBROUTINE PTNST5(PT,P0,G,DISC)
C
C     SATELLITE TX PATTERN FROM RARC 83 P.111,
C     BSS PATTERN
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      X1 = PT/P0
C
      IF (X1 .LE. 1.58)  GO TO 10
      IF (X1 .LE. 3.16)  GO TO 12
      IF (X1 .LE. 10.)  GO TO 14
C
      DISC = -42.5
      GO TO 40
C
 10   DISC = -12.0 * X1 * X1
      GO TO 40
C
 12   DISC = -30.
      GO TO 40
C
 14   DISC = -17.5-25.*ALOG10(X1)
      GO TO 40
C
  40  RETURN
      END
C
      SUBROUTINE PTNER1(PR,P0,F,G,DIREC)
C
C     FSS EARTH REVEIVER PATTERN FROM CCIR REPORT 391-4
C     ANTENNA DIAMETER 3 METERS, MAIN LOBE NOT GAUSSIAN
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      DPR = PR*DEGREE
      DP0 = P0 * DEGREE
      WAVEL = 300./F
      D=3.
      X1 = D/WAVEL
      G1 = 2. + 15.* ALOG10(X1)
      PM = 20./X1* SQRT(G-G1)
      PS = 15.85 / X1**0.6
C
```

```
      IF (DPR .LE. PM)  GO TO 50
      IF (DPR .LE. PS)  GO TO 60
      IF (DPR .LE. 48.)  GO TO 70
C
      DIREC = -10.
      GO TO 80
C
   50 DIREC = G- 2.5E-3 * X1*X1*DPR*DPR
      GO TO 80
C
   60 DIREC = G1
      GO TO 80
C
   70 DIREC = 32.-25.*ALOG10(DPR)
C
   80 RETURN
      END
C
      SUBROUTINE PTNER2(PR,P0,F,G,DIREC)
C
C     FSS EARTH REVEIVER PATTERN FROM CCIR REPORT 391-4
C     MAIN LOBE GAUSSIAN, ANTENNA DIAMETER 3 METERS,
C     MODIFIED FOR NON US COUNTRIES
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      DPR = PR*DEGREE
      X = PR/P0
      P2 = 10.**((32.+10.)/25.)
C
      IF (X.LE.0.5) THEN
      DIREC = G - 12.*X*X
      GO TO 80
      ELSE IF (DPR .GE. P2) THEN
      DIREC = -10.
      GO TO 80
      END IF
C
      DIREC = G - 12.*X*X
      D1 = 32. - 25.*ALOG10(DPR)
      IF (D1 .GE. DIREC) DIREC = D1
C
   80 RETURN
      END
C
      SUBROUTINE PTNER3(PR,P0,F,G,DIREC)
C
C     FSS EARTH REVEIVER PATTERN FROM CCIR REPORT 391-4
C     MAIN LOBE GAUSSIAN
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      DPR = PR*DEGREE
      X = PR/P0
      P2 = 10.**((29.+10.)/25.)
C
      IF (X.LE.1.) THEN
      DIREC = G - 12.*X*X
      GO TO 80
      ELSE IF (DPR .GE. P2) THEN
```

```
      DIREC = -10.
      GO TO 80
      END IF
C
      DIREC = G - 12.*X*X
      D1 = 29. - 25.*ALOG10(DPR)
      IF (D1 .GE. DIREC) DIREC = D1
C
   80 RETURN
      END
C
      SUBROUTINE PTNER4(PR,P0,F,G,DIREC)
C
C     FSS EARTH REVEIVER PATTERN FROM CCIR REPORT 391-4
C     MAIN LOBE GAUSSIAN, ANTENNA DIAMETER 4.5 METERS,
C     MODIFIED FOR US ONLY
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      DPR = PR*DEGREE
      X = PR/P0
      P2 = 10.**((29.+10.)/25.)
C
      IF (X.LE.1.) THEN
      DIREC = G - 12.*X*X
      GO TO 80
      ELSE IF (DPR .GE. P2) THEN
      DIREC = -10.
      GO TO 80
      END IF
C
      DIREC = G - 12.*X*X
      D1 = 29. - 25.*ALOG10(DPR)
      IF (D1 .GE. DIREC) DIREC = D1
C
   80 RETURN
      END
C
      SUBROUTINE PTNER5(PR,P0,F,G,DIREC)
C
C     FSS EARTH REVEIVER PATTERN FROM CCIR REPORT 391-4
C     MAIN LOBE GAUSSIAN, ANTENNA DIAMETER 4.5 METERS,
C     MODIFIED FOR US ONLY
C
      IMPLICIT INTEGER(I-N),REAL(A-H,O-Z)
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      DPR = PR*DEGREE
      X = PR/P0
      P2 = 10.**((29.+10.)/25.)
C
      IF (X.LE.1.) THEN
      DIREC = G - 12.*X*X
      GO TO 80
      ELSE IF (DPR .GE. P2) THEN
      DIREC = -10.
      GO TO 80
      END IF
C
      DIREC = G - 12.*X*X
      D1 = 29. - 25.*ALOG10(DPR)
```


C-3

```
      IF (D1 .GE. DIREC) DIREC = D1
C
   80 RETURN
      END
C
      SUBROUTINE VECCAL
C
C***  >> SET UP VECTORS FOR THE TEST POINTS <<
C     ***************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHIO(2),DCPHIO(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1           DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1             ADT(100),ADR(100)
C
C ***************************************************************
      DO 30  K = 1,2
C
C***   >> FIND RECTANGULAR COORDINATES OF ORBITAL LOCATION <<
C             ZO=0 FOR GEOSTATIONARY SATELLITES
C
        XO(K) = COS(RSLON(K))*GCR
```

```
          YO(K) = SIN(RSLON(K))*GCR
C
C***    >> FIND VECTOR FROM SATELLITE TO AIM POINT ON EARTH
C
          XOAC(K) = COS(BCLAT(K))
     1      *COS(BCLON(K))-XO(K)
          YOAC(K) = COS(BCLAT(K))*SIN(BCLON(K))-YO(K)
          ZOAC(K) = SIN(BCLAT(K))
C
C***    >> FIND RANGE FROM SATELLITE TO AIM POINT
C
          ROAC(K) = SQRT(XOAC(K)**2+YOAC(K)**2+ZOAC(K)**2)
C
   30       CONTINUE
        RETURN
        END
C
        SUBROUTINE SETUP(DELS)
C
C     COMPUTES RECTANGULAR COORDINATES OF THE TEST POINTS AND THE
C     SATELLITE AIMPOINTS AND ESTABLISHES THE SATELLITE LOCATIONS
C     RELATIVE TO DELS
C
C       **********************************************************
C
        IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
        CHARACTER*8 NAMESA,SANAME
C
        INTEGER APTNER,APTNET,APTNST,APTNSR
C
        COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                  PFD,ALOGE,ALN10,COIMIN
C
        COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
        COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                  XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
        COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                  UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                  IPTNET(2),IPTNST(2),IPTNSR(2)
C
        COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                  REFLAT(2),REFLON(2),AXR(2),
     2                        ORIENT(2),AXMAJ(2)
C
        COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                  DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
        COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                  ALPHA(2,20),ALPHA0(2,20)
C
        COMMON /DIA/    DT(2),DR(2)
C
        COMMON /LOC/    SLON
C
        COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                  YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
        COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
```

```
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C *************************************************************
C
      DO 10  N = 1,2
C
         DO 12  N1 = 1,NTPSA(N)
C        >>  FIND RECTANGULAR COORDINATES OF EARTH STATIONS   <<
C
C        X AXIS--POSITIVE X AXIS THROUGH POINT 0 DEGREES LONGITUDE
C        Y AXIS--POSITIVE Y AXIS THROUGH POINT 90 DEGREES EAST
C        Z AXIS--EARTH'S AXIS, POSITIVE Z AXIS THROUGH NORTH POLE
C
            XE(N,N1) = COS(RELAT(N,N1)) * COS(RELON(N,N1))
            YE(N,N1) = COS(RELAT(N,N1)) * SIN(RELON(N,N1))
            ZE(N,N1) = SIN(RELAT(N,N1))
C
  12     CONTINUE
C
C     FIND THE EARTH CENTERED RECTANGULAR COORDINATES OF THE AIMPOINT
C
            XB(N)=COS(BCLAT(N))*COS(BCLON(N))
            YB(N)=COS(BCLAT(N))*SIN(BCLON(N))
            ZB(N)=SIN(BCLAT(N))
C
 10   CONTINUE
C
C SEPARATE THE ORBITAL LOCATIONS OF THE 2 SATELLITES BY THE INITIAL
C TRIAL SOLUTION VALUE. THE ONE WHOSE SERVICE AREA IS FARTHEST EAST IS
C PUSHED FARTHEST EAST.
C
            IF (BCLON(2) .GT. BCLON(1)) THEN
                 DSLON(2) = SLON + DELS/2.0
                 DSLON(1) = SLON - DELS/2.0
            ELSE
                 DSLON(1) = SLON + DELS/2.0
                 DSLON(2) = SLON - DELS/2.0
            END IF
C
C  CONVERT THE ORBITAL LOCATIONS FROM DEGREES TO RADIANS
C
            RSLON(1) = DSLON(1) * RADIAN
            RSLON(2) = DSLON(2) * RADIAN
C
      RETURN
      END
C
      SUBROUTINE COILK(WCOIL)
C
      IMPLICIT INTEGER (I-L,N), REAL(A-H,M,O-Z)
C
      COMMON /CTOI/ COID(2),COIU(2)
C
C     THIS JUST FINDS THE WORST LINK C/I RATIO FOR THE 2 SATELLITES
C     THE EQUATIONS FIRST CONVERT THE C/I VALUES FROM DB TO RATIOS
C
      COIL1=-10.0*ALOG10(10.**(-COIU(1)/10.0)+10.**(-COID(1)/10.))
C
      COIL2=-10.0*ALOG10(10.**(-COIU(2)/10.0)+10.**(-COID(2)/10.))
C
```

```
      WCOIL=AMIN1(COIL1,COIL2)
      RETURN
      END
C
             SUBROUTINE  WRPH
C    THIS ROUTINE WRITES THE DELTA-PHI MATRIX TO BE USED IN THE
C    SWITCHING ALGORITHM. IT INCLUDES THE REDUNDANT ENTRIES FOR
C    MULTIPLE ADMINISTRATIONS WHICH HAVE THE SAME SERVICE AREA
C    FOR WHICH CALCULATIONS WERE SKIPPED IN THE MAIN PROGRAM.
C
C      ************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C ************************************************************
C
         ION = 0
         NUM = 0
         NGT2 = 0
```

Program DELTA (cont.)

```
          ITOTSA = 0
C
          DO 6  L = 1,NUMSAR
             IF  ( NUMSAT(L) .GT. 2 )  THEN
                ION = ION + NUMSAT(L)
                NGT2 = NGT2 + 1
             ENDIF
                ITOTSA = NUMSAT(L) + ITOTSA
 6        CONTINUE
C
              IKIM = (NGT2 * 2 ) + 1
              ION = ION + 1
C
          DO  7 J = 1,IPOS
C
          IM = 1
          NSAT1 = 1
          NSAT2 = NUMSAT(IM)
          IB = 2
          IC = 3
          ID = 1
          IE = 1
          IX = 1
          NGTT2 = NGT2
C
            DO  8 IBULL = 1,NGT2
C
              DO   9 I = NSAT1,NSAT2
                  ICAT = I
                  IY = IB
                  IL = IC
                  NSAT = NSAT2
                  IA = IE
                  NUM = IKIM
                     DO 31 IZ = 1,NGTT2
                        DO 41 K = ICAT,NSAT
                           DELPH(J,I,K) = DELP(J,IX,IY)
 41                     CONTINUE
                           IY = IY  + 2
                           ICAT = NSAT + 1
                           NSAT = NSAT + NUMSAT(IL)
 31                  CONTINUE
                        DO 51 K = ION,ITOTSA
                             DELPH(J,I,K) = DELP(J,IA,NUM)
                             NUM = NUM + 1
 51                     CONTINUE
 9               CONTINUE
C
                   IE = IE + 2
                   IM = IM + 2
                   IX = IX + 2
                   IB = IB + 2
                   NSAT1 = NSAT2 + 1
                   NSAT2 = NSAT1 + NUMSAT(IM) -1
                   IC = IC + 2
                   NGTT2 = NGTT2 - 1
 8          CONTINUE
 7        CONTINUE
C
          DO 34 J = 1,IPOS
             NUM = IKIM - 1
             DO 750  I = ION,ITOTSA
               NUMK = NUM
               NUM = NUM + 1
               NUMK = NUM + 1
               IR = I + 1
```

```
                DO 725  K = IR,ITOTSA
                  DELPH(J,I,K) = DELP(J,NUM,NUMK)
                  NUMK = NUMK + 1
725             CONTINUE
750          CONTINUE
C
          WRITE(10,951) DELPOS(J)
          DO 200 I = 1,ITOTSA -1
              WRITE(10,952) (DELPH(J,I,K),K=I+1,ITOTSA)
200            CONTINUE
34           CONTINUE
C
951   FORMAT(10X,F15.5)
952   FORMAT(13F5.2)
         RETURN
         END
C
      SUBROUTINE WRDM
C
C    THIS ROUTINE WRITES THE DELTA-S MATRIX TO BE USED IN THE
C    SWITCHING ALGORITHM. ITS COMPLEXITY IS CAUSED BY THE ROUTINES
C    USED TO AVOID REDUNDANT CALCULATIONS THAT ARE EXPLAINED IN THE
C    SUBROUTINE INDATA.
C
C     ***************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      INTEGER APTNER,APTNET,APTNST,APTNSR
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(2),NTPSA(2)
C
      COMMON /VECTOR/ DSLON(2),RSLON(2),XO(2),YO(2),
     1                XOAC(2),YOAC(2),ZOAC(2),ROAC(2)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(2),RGAIN(2),TGAIN(2),
     1                UCPHI0(2),DCPHI0(2),EIRP(2),IPTNER(2),
     2                IPTNET(2),IPTNST(2),IPTNSR(2)
C
      COMMON /MINELL/ BCLAT(2),BCLON(2),DBCLAT(2),DBCLON(2),
     1                REFLAT(2),REFLON(2),AXR(2),
     2                      ORIENT(2),AXMAJ(2)
C
      COMMON /TPOINT/ RELON(2,20),RELAT(2,20),DELON(2,20),
     1                DELAT(2,20),XE(2,20),YE(2,20),ZE(2,20)
C
      COMMON /ANGLES/ PHI(2,20),PHI0(2,20),THETA(2,20),
     1                ALPHA(2,20),ALPHA0(2,20)
C
      COMMON /DIA/    DT(2),DR(2)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(2),YB(2),ZB(2),XPO(2),YPO(2),ZPO(2),
     1                YP(2,2,20),ZP(2,2,20),YD(2,20),ZD(2,20)
C
      COMMON /MULTIP/ ADELON(100,20),ADELAT(100,20),
     1 ADBLON(100,100),ADBLAT(100,100),AELLOC(100,100),
     2 AORENT(100,100),AAXMAJ(100,100),
     3 AAXR(100,100),WELLOC(100),EELLOC(100),INTP(100),
     4 NELLOC(100),SANAME(100)
```

```
C
      COMMON /AREAS/ DELTS,INTSP,NUMSA,OPTION
C
      COMMON /SW/ DELM(100,100),DELMAX(100,100),DELP(20,100,100),
     1            DELPH(20,100,100),DELPOS(20),NUMSAT(100),IPOS
C
      COMMON /PTRN/ APTNER(100),APTNET(100),APTNST(100),APTNSR(100),
     1              ADT(100),ADR(100)
C
C *************************************************************
C
        ION = 0
        NUM = 0
        NGT2 = 0
        ITOTSA = 0
C
        DO 6  L = 1,NUMSAR
           IF  ( NUMSAT(L) .GT. 2 )  THEN
              ION = ION + NUMSAT(L)
              NGT2 = NGT2 + 1
           ENDIF
              ITOTSA = NUMSAT(L) + ITOTSA
 6      CONTINUE
C
           IKIM = (NGT2 * 2 ) + 1
           ION = ION + 1
C
        IM = 1
        NSAT1 = 1
        NSAT2 = NUMSAT(IM)
        IB = 2
        IC = 3
        ID = 1
        IE = 1
        IX = 1
        NGTT2 = NGT2
C
          DO  8 IBULL = 1,NGT2
C
            DO   9 I = NSAT1,NSAT2
                ICAT = I
                IY = IB
                IL = IC
                NSAT = NSAT2
                IA = IE
                NUM = IKIM
                   DO 31 IZ = 1,NGTT2
                      DO 41 K = ICAT,NSAT
                       DELMAX(I,K) = DELM(IX,IY)
 41                   CONTINUE
                        IY = IY  + 2
                        ICAT = NSAT + 1
                        NSAT = NSAT + NUMSAT(IL)
 31                CONTINUE
                      DO 51 K = ION,ITOTSA
                          DELMAX(I,K) = DELM(IA,NUM)
                          NUM = NUM + 1
 51                   CONTINUE
 9            CONTINUE
C
                IE = IE + 2
                IM = IM + 2
                IX = IX + 2
                IB = IB + 2
                NSAT1 = NSAT2 + 1
                NSAT2 = NSAT1 + NUMSAT(IM) -1
```

```
               IC = IC + 2
               NGTT2 = NGTT2 - 1
 8          CONTINUE
C
            NUM = IKIM - 1
            DO 750  I = ION,ITOTSA
              NUMK = NUM
              NUM = NUM + 1
              NUMK = NUM + 1
              IR = I + 1
                  DO 725  K = IR,ITOTSA
                    DELMAX(I,K) = DELM(NUM,NUMK)
                    NUMK = NUMK + 1
 725              CONTINUE
 750         CONTINUE
C
           DO 200 I = 1,ITOTSA -1
               WRITE(7,952) (DELMAX(I,K),K=I+1,ITOTSA)
 200          CONTINUE
C
 952   FORMAT(13F5.2)
            RETURN
            END
```

Appendix C

Program MISOUP: An Aggregate Interference Program

APPENDIX C

Program MISOUP: An Aggregate Interference Program

```
C
C                          PROGRAM MISOUP
C
C     THIS IS A NEW VERSION OF THE STREAMLINED SOUP PROGRAM TO CALCULATE
C     AGGREGATE CARRIER TO INTERFERENCE RATIOS (C/I) WHICH INCLUDES
C     UPLINK INTERFERENCE. MOST OF THE SUBROUTINES ARE THE SAME AS THOSE
C     FOUND IN IN THE DELTA-S (REQUIRED SATELLITE SEPARATION PROGRAM)
C
C     THE INPUT FILE TO THIS PROGRAM INCLUDES THE ORBITAL LOCATIONS
C     FOR THE SATELLITES, THE ANTENNA DATA FOR THE GROUND STATIONS AND
C     FOR THE SATELLITES, THE TEST POINTS WHICH DEFINE THE SERVICE AREAS
C     AND THE MINIMUM ELLIPSE DATA FOR THE ELLIPTICAL PATTERNS USED ON THE
C     SATELLITES.
C
C     THE OUTPUT FILE LISTS THE WORST SINGLE ENTRY C/I VALUES ON BOTH THE
C     UPLINK AND DOWNLINK FOR EVERY ADMINISTRATION. IT ALSO LISTS THE
C     WORST CASE AGGREGATE C/I VALUES ON BOTH THE UPLINK AND THE DOWNLINK.
C     FINALLY, IT LISTS A LINK AGGREGATE C/I VALUE
C
C     WRITTEN BY P. KOHNHORST,  4/87-5/87
C
C     ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C ************************************************************
C
      OPEN (UNIT=5,FILE='INFILE.DAT',TYPE='OLD')
      OPEN (UNIT=6,FILE='OUTFILE.DAT',TYPE='NEW')
C
C   INPUT NECESSARY CONSTANTS USED IN THE CALCULATIONS
C
      CALL ICONST
C
```

```
C    INPUT SATELLITE AND SERVICE AREA DATA
C
        CALL INDATA
C
C  CALL A SUBROUTINE TO INITIALIZE THE NECESSARY PARAMETERS
C
        CALL PARAM
C
C       DO AGGREGATE INTERFERENCE CALCULATION FOR ALL SIGNIFICANT
C       SOURCES OF INTERFERENCE. K IS THE DESIRED SATELLITE, I
C       IS THE INTERFERING SATELLITE
C
        DO 10     K=1,NUMSAR
C
           WRITE(6,100) NAMESA(K,1),DSLON(K)
 100       FORMAT(2X,'ADMINISTRATION: ',A6,'    SATELLITE LOCATION:',
     1            F7.2)
C
C      FIRST THE DOWNLINK INTERFERENCE
C
           CALL DOWNCOI(K,JDW,DCOI)
C
C      THEN THE UPLINK INTERFERENCE
C
           CALL UPCOI(K,UCOI)
C
C      THIS STATEMENT FINDS THE TOTAL LINK AGGREGATE C/I BY ASSUMING
C      THAT THE C/I RATIO AT THE OUTPUT OF THE SATELLITE IS THE SAME
C      AS THAT ON THE INPUT------NO ONBOARD PROCESSING
C
           COIAGG=-10.*ALOG10(10.**(-DCOI/10.)+10.**(-UCOI/10.))
C
           WRITE(6,110) DCOI,DELAT(K,JDW),DELON(K,JDW)
           WRITE(6,120) UCOI
           WRITE(6,130) COIAGG
C
  110      FORMAT(4X,' WORST AGGREGATE DOWNLINK C/I:',F7.2,' AT
     1     TEST POINT (',F6.2,1X,F7.2,')')
  120      FORMAT(4X,' WORST AGGREGATE UPLINK C/I:',F7.2)
  130      FORMAT(/,4X,' WORST LINK AGGREGATE C/I:',F7.2,//)
C
   10 CONTINUE
      END
C
      SUBROUTINE DOWNCOI(K,JDW,WCACOI)
C
C     THIS ROUTINE CALCULATES THE AGGREGATE DOWNLINK INTERFERENCE AT EVERY
C     TEST POINT IN THE SERVICE AREA OF SATELLITE K. IT RETURNS THE WORST VALUE
C     AND THE INDEX OF THE TEST POINT AT WHICH THE WORST VALUE OCCURED. IT
C     INCLUDES INTERFERENCE FROM ALL SATELLITES WITHIN 10 DEGREES OF THE
C     DESIRED SATELLITE.
C
C     ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
```

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```
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C ************************************************************
C
      WCACOI=1000.
C
C     LOOP OVER ALL TEST POINTS IN SERVICE AREA OF SATELLITE K
C
      DO 10     J=1,NTPSA(K)
          SUMINT=0.
          WDCI=1000.
C
C     CALL A SUBROUTINE TO FIND THE NUMERATOR OF THE C/I EQUATION
C               FOR TEST POINT J OF ADMINISTRATION K
C
          CALL DPWR(K,J,DEPR)
C
C                 LOOP OVER ALL INTERFERING SATELLITES
C
          DO 20    I=1,NUMSAR
C
C     SKIP IF SATELLITE I IS THE DESIRED SATELLITE OR MORE THAN 10 DEGREES
C                  AWAY FROM THE DESIRED SATELLITE
C
              IF ((I .NE. K) .AND.
     1        (ABS(DSLON(I)-DSLON(K)) .LT. 10.)) THEN
C
C     CALL A SUBROUTINE TO FIND THE DENOMINATOR OF THE SINGLE ENTRY
C                     C/I EQUATION FOR SATELLITE I
C
                  CALL DOWNINT(K,I,J,PWRINT)
C
C                 CALCULATE SINGLE ENTRY C/I
C
C     CHECK TO SEE IF SATELLITE I IS THE WORST SOURCE OF SINGLE ENTRY
C     INTERFERENCE SO FAR. IF SO, SAVE THIS C/I VALUE AND I
C
                  COI=DEPR-PWRINT
                  IF (COI .LT. WDCI) THEN
                     WDCI=COI
                     IWDTP=I
                  END IF
C
C     ADD INTERFERENCE FROM SATELLITE I TO THE SUMMATION OF SINGLE ENTRY
C                DOWNLINK INTERFERENCE POWERS AT POINT J
C
```

```
                SUMINT=SUMINT+10.**(PWRINT/10.)
             END IF
   20     CONTINUE
          SUMINT=10.*ALOG10(SUMINT)
C      CALCULATE AGGREGATE C/I AT THIS TEST POINT
          AGGCOI=DEPR-SUMINT
C
C     CHECK TO SEE IF THE AGGREGATE C/I AT TEST POINT J IS THE
C     LOWEST YET FOUND. IF SO SAVE THIS VALUE, THE INDEX OF THE TEST
C     POINT, THE INDEX OF THE WORST INTERFERING SATELLITE
C
          IF (AGGCOI .LT. WCACOI) THEN
             WCACOI=AGGCOI
             JDW=J
             WSECOI=WDCI
             IWDSE=IWDTP
          END IF
   10 CONTINUE
C
      WRITE(6,101)WSECOI,NAMESA(IWDSE,1)
 101  FORMAT(4X,'WORST DOWN SINGLE ENTRY C/I:',F6.2,' FROM:',A6)
C
      RETURN
      END
      SUBROUTINE UPCOI(K,UCOI)
C
C     THIS ROUTINE FINDS THE WORST CASE AGGREGATE C/I RATIO FOR
C     THE UPLINK OF ADMINISTRATION K'S SATELLITE LINK. IT ALSO
C     FINDS THE WORST CASE SINGLE ENTRY VALUE
C
C     ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
C ************************************************************
C
C   CALL A SUBROUTINE WHICH FINDS THE TEST POINT IN SATELLITE
C   K'S SERVICE AREA WHICH IS CLOSEST TO THE -3 DB CONTOUR OF
C   ITS SATELLITE ANTENNA. THIS VALUE IS LABELED DISMIN AND
C   IS THE NUMERATOR IN THE C/I EQUATION. THE LOCATION OF THE
C   DESIRED TRANSMITTER IS ALWAYS LOCATED AT THIS WORST POINT
C
      CALL MINDIS(K,DISMIN)
C
      WORSTCOI=100.0
      SUMINT=0.
C
C     THIS IS A LOOP OVER ALL INTERFERING SATELLITES
C
      DO 20      I=1,NUMSAR
C
C   SKIP IF THE SATELLITES ARE MORE THAN 10 DEGREES AWAY
C   OR THE DESIRED SATELLITE AND INTERFERING SATELLITES
C   ARE THE SAME
C
           IF ((I .NE. K) .AND.
     !         (ABS(DSLON(I)-DSLON(K)) .LT. 10.)) THEN
               UINT=-50.0
C
C   THIS LOOP CALCULATES THE DENOMINATOR OF THE C/I EQUATION
C   FOR ALL POSSIBLE TEST POINTS FOR THE INTERFERING TRANSMITTER
C
               DO 30     J=1,NTPSA(I)
                    CALL UPINT(K,I,J,PWRINT)
C
C  CHECK IF THIS TEST POINT IS THE SITE FOR THE INTERFERING TRANSMITTER
C  WHICH PROVIDES THE MOST INTERFERENCE
C
                    IF (PWRINT .GT. UINT) THEN
                       UINT=PWRINT
                    END IF
  30           CONTINUE
C
C  COMPUTE WORST SINGLE ENTRY C/I FOR ADMINISTRATION K WITH INTERFERENCE
C  FROM ADMINISTRATION I. SAVE THIS IF IT IS THE WORST VALUE FOUND FOR
C  ANY ADMINISTRATION
C
             SECOI = DISMIN-UINT
             IF (SECOI .LT. WORSTCOI) THEN
                WORSTCOI=SECOI
                IWUPI=I
             END IF
C
C  ADD WORST VALUE OF INTERFERENCE TO TOTAL INTERFERENCE
C
                SUMINT=SUMINT+10.**(UINT/10.)
            END IF
  20  CONTINUE
C
C  FIND TOTAL INTERFERENCE IN dB
C
      SUMINT=10.*ALOG10(SUMINT)
C
C  FIND THE AGGREGATE C/I RATIO FOR ADMINISTRATION K
C
      UCOI=DISMIN-SUMINT
C
      WRITE(6,201)WORSTCOI,NAMESA(IWUPI,1)
 201  FORMAT(4X,'WORST UP SINGLE ENTRY :',F7.2,' FROM:',A6)
C
```

```
      RETURN
      END
C
      SUBROUTINE MINDIS(K,DISMIN)
C
C     FIND THE NUMERATOR OF THE AGGREGATE UPLINK C/I
C     EXPRESSION. THIS IS DONE BY FINDING THE WORST CASE---
C     THAT IS, THE DESIRED EARTH TRANSMITTER THAT IS CLOSEST
C     TO THE -3 dB CONTOUR OF THE RECEIVING ANTENNA.
C
C     ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C ************************************************************
C
      GK=GAINS(K)
      DISMIN = 100.
C
      DO 10     J=1,NTPSA(K)
C
C   FIRST FIND THE NEEDED ANGLES:
C
C        THIS FINDS THE OFF AXIS ANGLE AS SEEN AT SATELLITE K
C        BETWEEN ITS AIMPOINT AND TEST POINT J
         CALL KPHI(K,K,J,PH)
C
C        THIS FINDS THE ELLIPTICAL HALF POWER BEAMWIDTH FOR
C        THE RECEIVING ANTENNA OF K IN THE DIRECTION OF J
         CALL XPHI0(K,K,J,PO)
C
C   NOW, FIND THE RECEIVING DISCRIMINATION AND COMPARE IT TO
C   THE WORST VALUE
C
```

```
      GO TO(110,120,130,140,150),IPTNST(K)
C
 110    CALL PTNST1(PH,PO,GK,RDISC)
      GOTO 160
C
 120    CALL PTNST2(PH,PO,GK,RDISC)
      GOTO 160
C
 130    CALL PTNST3(PH,PO,GK,RDISC)
      GOTO 160
C
 140    CALL PTNST4(PH,PO,GK,RDISC)
      GOTO 160
C
 150    CALL PTNST5(PH,PO,GK,RDISC)
C
 160    IF (RDISC .LT. -3.) THEN
         RDISC=-3.
      END IF
C
      IF (RDISC .LT. DISMIN) THEN
         DISMIN=RDISC
      END IF
C
  10  CONTINUE
      RETURN
      END
C
      SUBROUTINE PARAM
C     ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C *************************************************************
```

```
C
C     FIND THE UPLINK AND DOWNLINK WAVELENGTHS
            DLAMDA=3.E+08/(DFREQ*1.0E+09)
            ULAMDA=3.E+08/(UFREQ*1.0E+09)
            X2=223./180.
C
      DO 10     K=1,NUMSAR
            DO 20          J=1,NTPSA(K)
C
C   FIND RECTANGULAR COORDINATES OF THE EARTH STATIONS
C
C   X AXIS---------POSITIVE X AXIS THROUGH POINT 0 DEG. LONGITUDE
C   Y AXIS---------POSITIVE Y AXIS THROUGH POINT 90 DEG. EAST
C   Z AXIS---------EARTH'S AXIS, POSITIVE Z IS NORTH POLE
C
                 XE(K,J)=COS(RELAT(K,J))*COS(RELON(K,J))
                 YE(K,J)=COS(RELAT(K,J))*SIN(RELON(K,J))
                 ZE(K,J)=SIN(RELAT(K,J))
C
   20       CONTINUE
C
C      FIND THE EARTH CENTER POINTS OF THE AIMPOINT
C
            XB(K)=COS(BCLAT(K))*COS(BCLON(K))
            YB(K)=COS(BCLAT(K))*SIN(BCLON(K))
            ZB(K)=SIN(BCLAT(K))
C
C  FIND THE EARTH CENTER POINTS OF THE SATELLITE LOCATION
C
            XO(K)=COS(RSLON(K))*GCR
            YO(K)=SIN(RSLON(K))*GCR
C
C FIND THE COMPONENTS OF THE VECTOR FROM THE AIMPOINT TO THE SATELLITE
C
            XOAC(K)=COS(BCLAT(K))*COS(BCLON(K))-XO(K)
            YOAC(K)=COS(BCLAT(K))*SIN(BCLON(K))-YO(K)
            ZOAC(K)=SIN(BCLAT(K))
C
C FIND THE RANGE FROM THE AIMPOINT TO THE SATELLITE
C
            ROAC(K)=SQRT(XOAC(K)**2.+YOAC(K)**2.+ZOAC(K)**2.)
C
            CALL REFCAL(K)
C
C FIND THE SATELLITE ANTENNA GAIN
C
            GAINS(K)=10.*ALOG10(EAP*AXR(K)
     !                *(PI*223./180./AXMAJ(K))**2.)
C
            X0=DR(K)/DLAMDA
            X1=DT(K)/ULAMDA
C
C    FIND THE RECEIVNG AND TRANSMITTING GAIN FOR THE ANTENNAS
C    OF ADMINISTRATION K'S GROUND STATIONS
C
            RGAIN(K)=10.0*ALOG10(PI*PI*EAP*X0*X0)
            TGAIN(K)=10.0*ALOG10(PI*PI*EAP*X1*X1)
C
C    FIND THE UPLINK AND DOWNLINK HALF POWER BEAMWIDTHS FOR THE
C    ANTENNAS OF ADMINISTRATION K'S GROUND STATIONS
C
            UCPHI0(K)=X2/X1
            DCPHI0(K)=X2/X0
C
C    FIND THE EFFECTIVE ISOTROPICALLY RADIATED POWER FOR THE DOWNLINK
C    OF ADMINISTRATION K. IT IS ASSUMED IN THIS PROGRAM THAT EVERY
```

```
C   ADMINISTRATION HAS THE SAME POWER FLUX DENSITY AT THE AIMPOINT
C   OF ITS SERVICE AREA.
C
          EIRP(K)=PFD+10.*ALOG10(4.*PI*ROAC(K)*ROAC(K)*ER*ER)
C
   10 CONTINUE
C
      RETURN
      END
C
      SUBROUTINE INDATA
C
C  THIS IS A SUBROUTINE WHICH INPUTS PARAMETERS DESCRIBING THE SERVICE
C  AREAS, THE SATELLITE AND GROUND STATION ANTENNAS, THE FEASIBLE
C  ORBITAL ARCS AND THE ELLIPSE DATA IF ELLIPTICAL PATTERNS ARE
C  BEING USED.
C      ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C ***************************************************************
C
      READ(5,*) NUMSAR,COIMIN,UFREQ,DFREQ
  100 FORMAT(I5,F5.1,F6.2,F6.2)
C
      DO 10     NS=1,NUMSAR
C
         READ(5,110) NAMESA(NS,1),NAMESA(NS,2)
  110    FORMAT(A6,A6)
C
         READ(5,*) DSLON(NS)
  115    FORMAT(2X,F7.2)
         RSLON(NS)=RADIAN*DSLON(NS)
C
```

```
          READ(5,*) IPTNER(NS),IPTNET(NS),IPTNST(NS),IPTNSR(NS)
 120      FORMAT(2X,I3,I3,I3,I3)
C
          READ(5,*) DT(NS),DR(NS)
 125      FORMAT(2X,F7.2,F7.2)
C
          READ(5,*) NTPSA(NS)
 130      FORMAT(2X,I5)
C
          DO 20 K=1,NTPSA(NS)
               READ(5,*) DELAT(NS,K),DELON(NS,K)
 140           FORMAT(2X,F7.2,F7.2)
               RELAT(NS,K)=DELAT(NS,K)*RADIAN
               RELON(NS,K)=DELON(NS,K)*RADIAN
  20      CONTINUE
C
          READ(5,*) DBCLAT(NS),DBCLON(NS),ORAN,AXMAJ(NS),AMN
 150      FORMAT(2X,F6.2,F7.2,F6.2,F6.2,F6.2)
C
          BCLAT(NS)=RADIAN*DBCLAT(NS)
          BCLON(NS)=RADIAN*DBCLON(NS)
          ORIENT(NS)=RADIAN*ORAN
          AXR(NS)=AXMAJ(NS)/AMN
          AXMAJ(NS)=RADIAN*AXMAJ(NS)
  10  CONTINUE
      RETURN
      END
      SUBROUTINE DOWNINT(K,I,J,PWRINT)
C
C     ****************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHIO(100),DCPHIO(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C ****************************************************************
```

```
C
C      THIS IS A SUBROUTINE TO CALCULATE THE DENOMINATOR OF THE
C      DOWNLINK C/I EQUATION FOR A TRANSMISSION FROM THE SATELLITE
C      OF ADMINISTRATION K TO TEST POINT J IN THE SERVICE AREA OF K
C      WITH THE SATELLITE FROM ADMINISTRATION I INTERFERING.
C
C      FIRST, CALCULATE THE NECESSARY ANGLES:
C         THE ELLIPTICAL HALF POWER BEAMWIDTH FOR THE BEAM OF SATELLITE
C         I IN THE DIRECTION OF TEST POINT J
       CALL XPHI0(I,K,J,AO)
C
C         THE OFF AXIS ANGLE AS SEEN BY SATELLITE I FROM THE AIMPOINT OF
C         I TO TEST POINT J
       CALL KPHI(I,K,J,AL)
C
C         THE ANGLE BETWEEN THE TWO SATELLITES, I AND K, AS SEEN FROM TEST
C         POINT J OF ADMINISTRATION K
       CALL ZPHI(I,K,J,TH)
C
       GI=GAINS(I)
C
C      FIND THE INTERFERING SATELLITE TRANSMITTING DISCRIMINATION
C
       GO TO(110,120,130,140,150),IPTNST(I)
C
 110   CALL PTNST1(AL,AO,GI,TDISC)
       GOTO 160
C
 120   CALL PTNST2(AL,AO,GI,TDISC)
       GOTO 160
C
 130   CALL PTNST3(AL,AO,GI,TDISC)
       GOTO 160
C
 140   CALL PTNST4(AL,AO,GI,TDISC)
       GOTO 160
C
 150   CALL PTNST5(AL,AO,GI,TDISC)
C
C  FIND THE RECEIVING ANTENNA DISCRIMINATION FOR THE GROUND STATION
C  AT TEST POINT J RECEIVING THE INTERFERING SIGNAL FROM I
C
 160   GO TO(210,220,230,240,250),IPTNER(K)
C
 210   CALL PTNER1(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
       GOTO 260
C
 220   CALL PTNER2(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
       GOTO 260
C
 230   CALL PTNER3(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
       GOTO 260
C
 240   CALL PTNER4(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
       GOTO 260
C
 250   CALL PTNER5(TH,DCPHI0(K),DFREQ,RGAIN(K),RDIR)
C
C CALCULATE DISTANCE FROM INTERFERING SATELLITE I TO TEST POINT J
C
 260   XOAIJ=XE(K,J)-XO(I)
       YOAIJ=YE(K,J)-YO(I)
       ZOAIJ=ZE(K,J)
       ROAIJ=SQRT(XOAIJ*XOAIJ+YOAIJ*YOAIJ+ZOAIJ*ZOAIJ)
C
C      FIND THE DENOMINATOR OF THE C/I CALCULATION IN dB
```

(Program MISOUP cont.)

```
C
      PWRINT=EIRP(I)+TDISC+RDIR-20.0*ALOG10(ROAIJ*ER)
C
      RETURN
      END
C
      SUBROUTINE UPINT(K,I,J,PWRINT)
C
C     ***************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C ***********************************************************
C
C   THIS IS A SUBROUTINE TO CALCULATE THE DENOMINATOR IN THE
C   UPLINK C/I EQUATION FOR THE UPLINK TRANSMISSION FROM THE
C   SERVICE AREA OF ADMINISTRATION K RECEIVING INTERFERENCE
C   FROM AN UPLINK TRANSMISSION FROM TEST POINT J IN THE
C   SERVICE AREA OF ADMINISTRATION I
C
C   FIRST, CALCULATE THE NEEDED ANGLES:
C
C   THIS FINDS THE OFF AXIS ANGLE AS SEEN BY THE RECEIVING ANTENNA
C   OF SATELLITE K, BETWEEN THE AIMPOINT OF K'S SERVICE AREA AND
C   THE POINT J IN THE SERVICE AREA OF I
      CALL KPHI(K,I,J,AL)
C
C   THIS FINDS THE ELLIPTICAL HALF POWER BEAMWIDTH FOR THE RECEIVING
C   ANTENNA OF SATELLITE K IN THE DIRECTION OF THE INTERFERING TRANSMITTER
C   AT J
      CALL XPHI0(K,I,J,AO)
C
C   THIS FINDS THE TOPOCENTRIC ANGLE BETWEEN THE SATELLITES AS SEEN AT THE
C   TRANSMITTING ANTENNA AT TEST POINT J IN THE SERVICE AREA OF I
```

```
      CALL ZPHI(K,I,J,TH)
C
C    FIND THE DISCRIMINATION FOR THE RECEIVING ANTENNA OF SATELLITE K
C    TO THE INTERFERING SIGNAL
C
      GO TO(11,12,13,14,15)IPTNSR(K)
C
   11 CALL PTNST1(AL,AO,GAINS(K),RDISC)
      GOTO 20
C
   12 CALL PTNST2(AL,AO,GAINS(K),RDISC)
      GOTO 20
C
   13 CALL PTNST3(AL,AO,GAINS(K),RDISC)
      GOTO 20
C
   14 CALL PTNST4(AL,AO,GAINS(K),RDISC)
      GOTO 20
C
   15 CALL PTNST5(AL,AO,GAINS(K),RDISC)
C
   20 GO TO(110,120,130,140,150),IPTNET(I)
C
C   FIND THE TRANSMITTING DIRECTIVITY OF THE ANTENNA AT
C   TEST POINT J
C
  110 CALL PTNER1(TH,UCPHI0(I),UFREQ,TGAIN(I),TDIRC)
      GOTO 160
C
  120 CALL PTNER2(TH,UCPHI0(I),UFREQ,TGAIN(I),TDIRC)
      GOTO 160
C
  130 CALL PTNER3(TH,UCPHI0(I),UFREQ,TGAIN(I),TDIRC)
      GOTO 160
C
  140 CALL PTNER4(TH,UCPHI0(I),UFREQ,TGAIN(I),TDIRC)
      GOTO 160
C
  150 CALL PTNER5(TH,UCPHI0(I),UFREQ,TGAIN(I),TDIRC)
C
C   SUBTRACT THE ON AXIS GAIN OF THE INTERFERING TRANSMITTING
C   ANTENNA FROM THE CALCULATED DIRECTIVITY TO FIND THE
C   TRANSMITTING DISCRIMINATION
C
  160 TDISC=TDIRC-TGAIN(I)
C
C   FIND THE DENOMINATOR OF THE UPLINK C/I EQUATION
C
      PWRINT=RDISC+TDISC
C
      RETURN
      END
      SUBROUTINE DPWR(K,J,DESPWR)
C
C     THIS CALCULATES THE NUMERATOR OF THE DOWNLINK C/I EQUATION
C     AT TEST POINT J IN THE SERVICE AREA OF ADMINISTRATION K
C     ******************************************************************
C
      IMPLICIT INTEGER(I-L,N),REAL(A-H,M,O-Z)
C
      CHARACTER*8 NAMESA,SANAME
C
      REAL LINKMG
C
      COMMON /CONSTS/ E,PI,RADIAN,DEGREE,GCR,ER,ERDB,EAP,
     1                PFD,ALOGE,ALN10,COIMIN
```

```
C
      COMMON /PARAMS/ NUMSAR,NAMESA(100,2),NTPSA(100)
C
      COMMON /VECTOR/ DSLON(100),RSLON(100),XO(100),YO(100),
     1                XOAC(100),YOAC(100),ZOAC(100),ROAC(100)
C
      COMMON /VARBLS/ UFREQ,DFREQ,GAINS(100),RGAIN(100),TGAIN(100),
     1                UCPHI0(100),DCPHI0(100),EIRP(100),IPTNER(100),
     2                IPTNET(100),IPTNST(100),IPTNSR(100)
C
      COMMON /MINELL/ BCLAT(100),BCLON(100),DBCLAT(100),DBCLON(100),
     1                REFLAT(100),REFLON(100),AXR(100),
     2                ORIENT(100),AXMAJ(100)
C
      COMMON /TPOINT/ RELON(100,20),RELAT(100,20),DELON(100,20),
     1                DELAT(100,20),XE(100,20),YE(100,20),ZE(100,20)
C
      COMMON /DIA/    DT(100),DR(100)
C
      COMMON /LOC/    SLON
C
      COMMON /COORD/  XB(100),YB(100),ZB(100),
     1                XPO(100),YPO(100),ZPO(100)
C
      COMMON /AREAS/ NUMSA
C
C ***********************************************************
C
C FIRST FIND THE NEEDED ANGLES:
C
C   THIS FINDS THE OFF AXIS ANGLE AS SEEN BY SATELLITE K FROM
C   ITS AIMPOINT TO TEST POINT J
      CALL KPHI(K,K,J,PH)
C
C   THIS FINDS THE ELLIPTICAL HALF POWER BEAMWIDTH FOR THE
C   BEAM OF SATELLITE K IN THE DIRECTION OF TEST POINT J
      CALL XPHI0(K,K,J,PO)
C
      GK=GAINS(K)
C
C   FIND THE TRANSMITTING DISCRIMINATION
C
      GO TO(10,20,30,40,50),IPTNST(K)
C
 10   CALL PTNST1(PH,PO,GK,TDISC)
      GOTO 60
C
 20   CALL PTNST2(PH,PO,GK,TDISC)
      GOTO 60
C
 30   CALL PTNST3(PH,PO,GK,TDISC)
      GOTO 60
C
 40   CALL PTNST4(PH,PO,GK,TDISC)
      GOTO 60
C
 50   CALL PTNST5(PH,PO,GK,TDISC)
C
 60   IF (TDISC .LT. -3.) THEN
         TDISC=-3.
      END IF
C
C     CALCULATE DISTANCE FROM SATELLITE TRANSMITTER TO EARTH RECEIVER
C
      XOAKJ=XE(K,J)-XO(K)
      YOAKJ=YE(K,J)-YO(K)
```

```
      ZOAKJ=ZE(K,J)
      ROAKJ=SQRT(XOAKJ*XOAKJ+YOAKJ*YOAKJ+ZOAKJ*ZOAKJ)
C
C     CALCULATE NUMERATOR OF C/I EQUATION FOR THE DOWNLINK
C
      DESPWR=EIRP(K)+RGAIN(K)+TDISC-20.0*ALOG10(ROAKJ*ER)
C
      RETURN
      END
C
```

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